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The Basic Technology of the Pulp and Paper Industry and its Environmental Protection Practices

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THE BASIC TECHNOLOGY OF THE PULP AND PAPER INDUSTRY AND ITS ENVIRONMENTAL PROTECTION PRACTICES

prepared by

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for the

Environmental Protection Programs Directorate
Environmental Protection Service
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ABSTRACT

The technology of pulp and paper manufacture in Canada is described with particular reference to environmental protection aspects. The history and scale of the pulp and paper industry are outlined briefly, and all major manufacturing processes and equipment described. The sources of atmospheric emissions, effluent discharges and solid wastes are identified and typical data reported for the principal process units.

In-plant measures used to reduce the impact of pulp and paper manufacture on the environment are incorporated in the process descriptions. The external effluent treatment systems and air pollution control equipment employed in the industry are reviewed, and typical cost and performance data presented.

A short bibliography and an extensive glossary of pulp and paper industry terminology are included.

RÉSUMÉ

Les techniques de fabrication des pâtes et papiers utilisées au Canada sont décrites, et une attention particulière est accordée à la protection de l'environnement. L'histoire et l'envergure de l'industrie des pâtes et papiers sont esquissées brièvement; de plus, tous les principaux procédés de fabrication ainsi que l'équipement utilisé sont décrits. Les sources des émissions atmosphériques, des effluents et des déchets solides sont identifiées; par ailleurs, le document contient des données typiques concernant les principales unités de traitement.

Les dispositions appliquées en usine en vue de réduire les incidences de la fabrication des pâtes et papiers sur l'environnement sont intégrées aux descriptions des procédés. Les systèmes externes de traitement des effluents et les dispositifs de lutte contre la pollution atmosphérique utilisés dans l'industrie sont passés en revue; en outre, des données sur le rendement et les coûts typiques sont présentées.

Finalement, le document contient une courte bibliographie et un vaste glossaire de l'industrie des pâtes et papiers.

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1 INTRODUCTION

This manual is intended to further the understanding of the basic technology in the pulp and paper industry with respect to environmental protection. It describes the sources of waste discharges and the control measures practiced, and provides an appreciation of the costs of environmental protection measures. It is written for Environmental Protection Service (EPS) field representatives whose responsibility involves pulp and paper mills and others who are concerned with the design and operation of environmental systems in the industry. Any comments concerning the content of the manual are welcome and should be directed to Mr. John Betts, Industrial Progams Branch, EPS.

The current version is an update of "The Basic Technology of the Pulp and Paper Industry and its Waste Reduction Practices" (Training Manual EPS 6-WP-74-3), incorporating also "Air Pollution Emissions and Control Technology: Wood Pulping Industry" (EPS 3-AP-77-6), and reflecting the technological evolution and economic changes in the industry since the early 1970s. The format and layout of the 1975 manual have been retained as far as possible for the convenience of users familiar with the previous version.

Typical values for the quantities of wastes produced at each point have been indicated wherever possible. However, users must recognize that such data is invariably site-specific, so it must be interpreted with due consideration for local conditions and data.

An attempt has also been made to provide some knowledge of the economic constraints imposed on mills as they strive to meet environmental standards. All costs cited are in 1983 Canadian dollars and, in the case of capital costs, include the relevant structures, equipment, installation costs, overheads, engineering and project management costs. The above-mentioned caution on the site-specific nature of data on waste quantities is even more applicable to costs.

The International System of Units (commonly abbreviated SI), as defined in the "Canadian Metric Practice Guide" prepared by the Canadian Standards Association (CAN-Z234), has been used to express all numerical data. Tonne (abbreviated as t) refers to a metric tonne, or 1 000 kg. Refer to the glossary for definitions of other abbreviations.

2 OVERVIEW OF THE CANADIAN PULP AND PAPER INDUSTRY

2.1 National Importance

Traditionally, the pulp and paper industry and related wood products industries have represented a cornerstone of Canadian economic life. In 1981, the annual production of the approximately 144 plants in Canada had a value of almost $12 billion. The purchasing power created by this money in the economy would represent about $22 billion of national income compared to Canada's gross national product of around $330 billion.

The pulp and paper industry is Canada's third largest industrial employer, providing about 83 000 factory and office jobs. If one includes woodlands workers, this would likely make the pulp and paper industry the largest single employer.

Being an export nation, Canada sells abroad about 50% of the value of the goods and services it produces. Pulp, paper and forest products represent the largest dollar value of Canadian exports, exceeding the value of such other exports as minerals, petroleum and agricultural products. Of the total exports, pulp and paper products represent about 10%. Table 1 summarises Canadian production and exports in 1981. It is quite apparent that of the over 21 million tonnes produced, over 78% is exported.

TABLE 1 1981 CANADIAN PRODUCTION AND EXPORTS

Product Type	1981 Production thousand tonnes	1981 Exports thousand tonnes
Newsprint	8 707	7 987
Wood Pulp	7 579	6 752
Paperboard	2 193	762
Writing Papers	1 529	573
Tissue and Sanitary Paper	153	29
Wrapping Paper	495	207
Building Board and Paper	410	44
Secondary Fibre		116
Totals	21 066	16 470

The export destinations for Canadian pulp and paper products in 1981 are listed in Table 2. It is clear that this industry is very dependent on product demand in

TABLE 2 EXPORT DESTINATIONS OF CANADIAN PULP AND PAPER PRODUCTS IN 1981

	Thousand Tonnes	Change Since 1972
United States	10 794	+4%
United Kingdom	973	-27%
Western Europe	2 031	+50%
Japan	780	+59%
Latin America	833	+10%
All others	1 060	+30%

other countries. It is also quite apparent in this table that the United States is the industry's best customer and buys over 65% of its exports.

The long-term projected world demand for newsprint and all major products is rising, but so is the production capacity of most of Canada's competitors. In particular, Canadian exports to the U.S. have hardly risen over the past 10 years since most of the increase in U.S. demand has been satisfied internally. Due to a combination of good quality wood resources and manufacturing know-how, Canadian products are generally considered good by overseas customers. However, cost is a major factor in determining the quantity of pulp and paper that can be exported; Canadian costs have risen dramatically in the past 10 years, exerting a brake on export expansion.

Figure 1 indicates the changes that have occurred over the past 50 years in production rates for the major products. The substantial increase in kraft production is apparent, as is the recent emergence of thermomechanical pulp, while sulphite production has decreased.

2.2 General Pollution Abatement Situation

During the 1960s, the pulp and paper industry, in spite of its growth, reduced the level of its suspended solids discharges by about 50%. A more modest reduction of about 24% of biochemical oxygen demand (BOD) discharges was achieved in the same period.

The further reductions in BOD and suspended solids achieved from 1969 to 1980 are shown in Figure 2. A detailed breakdown by region of this data can be found in "Status Report on Abatement of Water Pollution from the Canadian Pulp and Paper Industry - 1980" (EPS 3-WP-82-3).

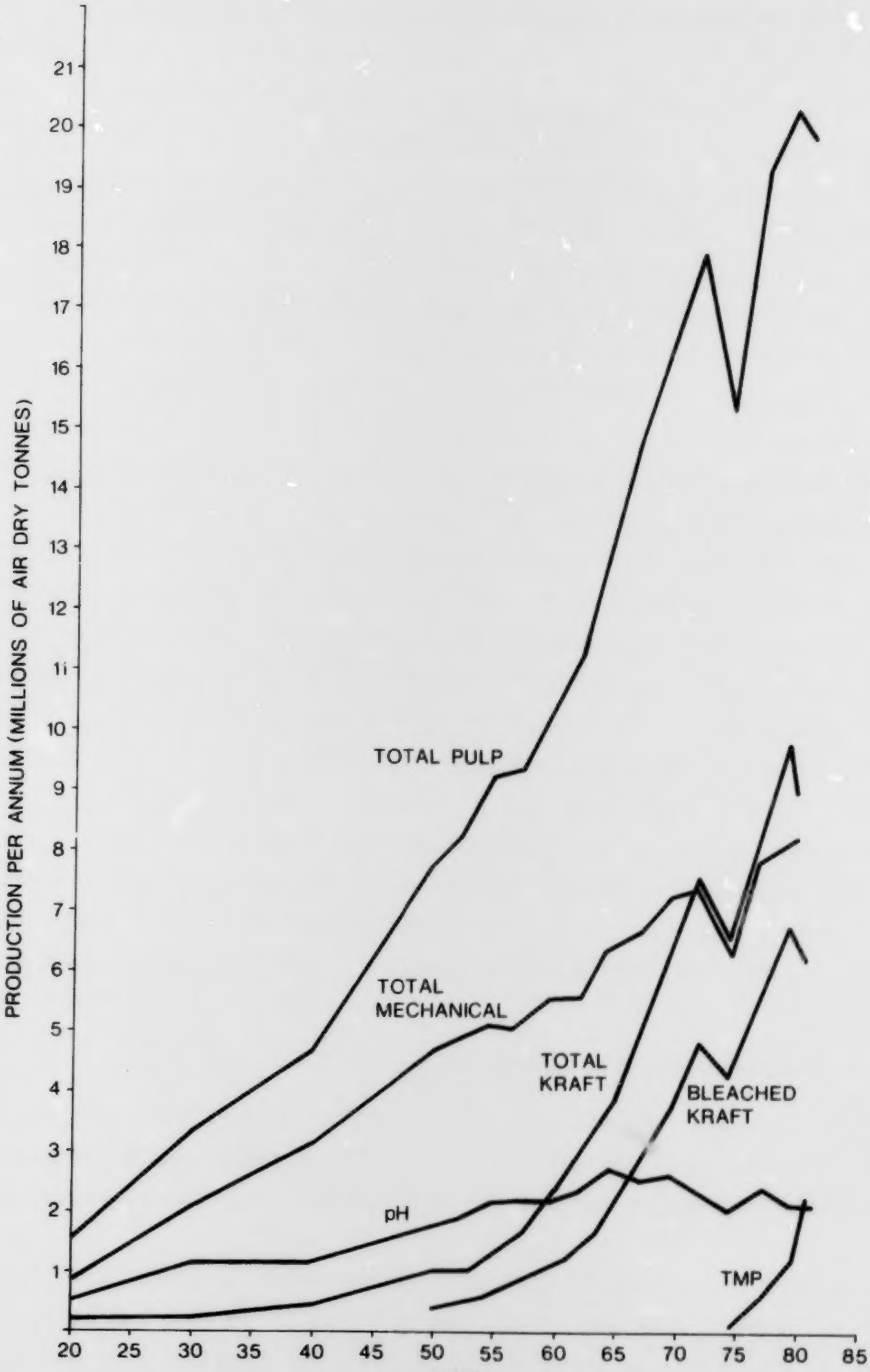

FIGURE 1 PULP PRODUCTION IN CANADA FROM 1920 to 1981

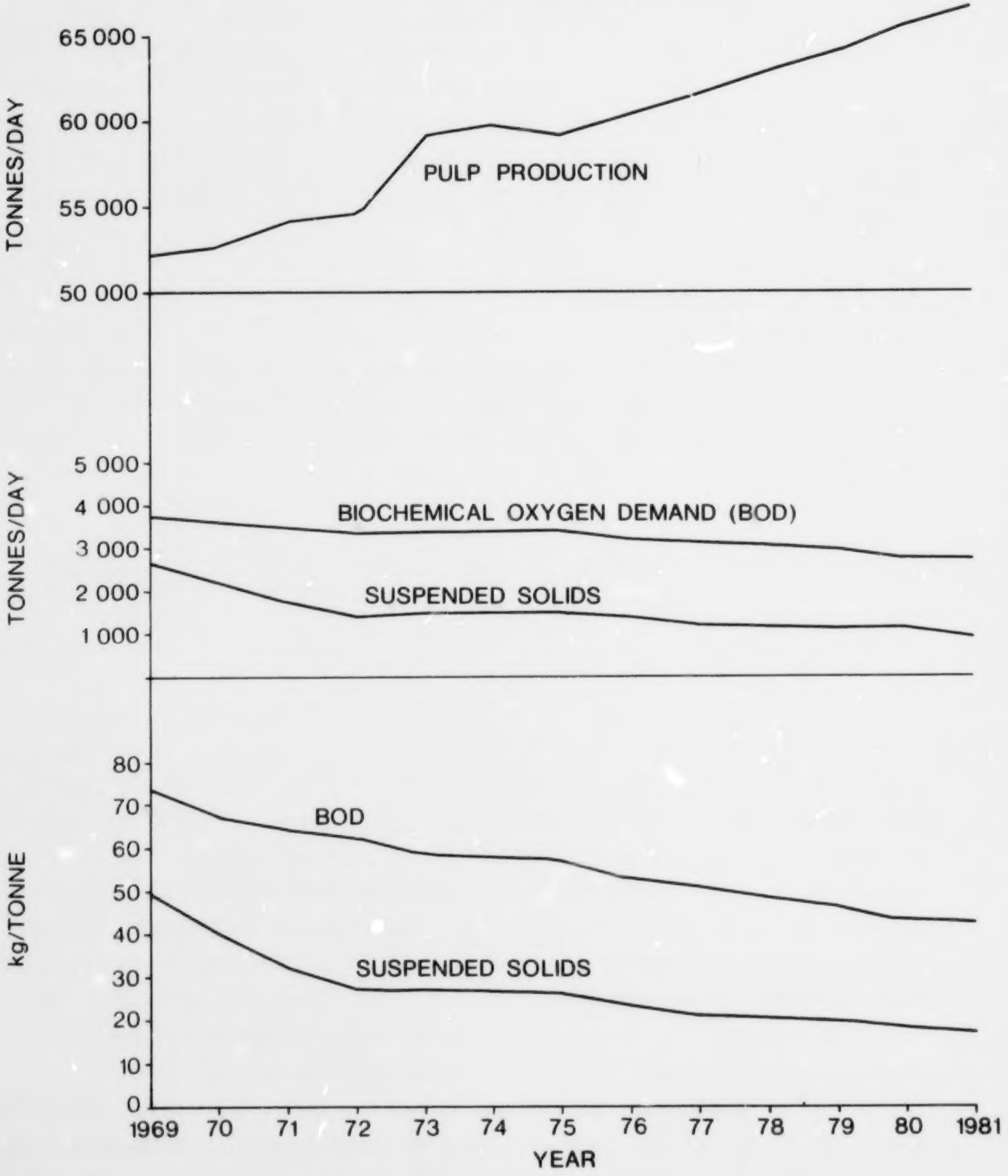

FIGURE 2 PULP PRODUCTION VS BOD AND SUSPENDED SOLIDS DISCHARGES (1969-1981)

2.3 Environmental Regulations

Federal, provincial and local authorities all have some jurisdiction over the environmental aspects of the pulp and paper industry. Local authorities have not played a significant part in regulating discharges from mills. However, all provinces with a pulp and paper industry have formed environmental protection organizations within their administrative structures and have enacted environmental control legislation specific to the pulp and paper industry.

Speaking very generally, the provincial regulations that apply to the industry are compatible with the federal regulations and guidelines. However, in some cases they are more stringent and in others they address concepts that do not exist in the federal regulations or guidelines. For example, Ontario has a regulation which limits the ambient concentrations of various gaseous pollutants at points of impingement outside the mill, as calculated by a mathematical technique defined in the regulation.

Detailed information on provincial regulations is available from the appropriate provincial regulatory authority.

2.3.1 Effluent Discharges. The federal government has direct authority over the discharges to watercourses and has passed legislation specific to pulp and paper liquid effluent discharges (see EPS 1-WP-72-1 and EPS 1-WP-72-2). The policy is containment at source through the use of the best practicable control technology.

2.3.2 Gaseous Emissions. In Canada, the control of air pollution from stationary sources is usually the direct responsibility of the provinces. (Exceptions for stationary air pollution sources include the situations described in Sections 7 and 9-18 of the Clean Air Act.) Federal authority covers certain fields such as control of health hazards, transborder air pollution, and federal establishments. In pursuing the objective of promoting a uniform approach to pollution control in Canada, the federal government is authorized under the Clean Air Act to develop and publish national emission guidelines. The purpose of the guidelines is to set emission limitations which might be looked upon as national "baselines" and considered by provincial governments as minimum standards on which to base their regulations. The philosophy behind these guidelines is also containment at source through the use of the best practicable control technology.

For the pulp and paper industry, air pollution control legislation in the form of regulations, guidelines, and objectives has been promulgated or is being developed by many regulatory authorities. A summary of the emission limits laid down by some of these authorities is shown in Tables 19 and 20. There is a similarity in the limits proposed, although variations in the method and extent of application exist.

National Guidelines are intended to be emission limits for all periods of operation except during start-up or shutdown or periods of upset operations. Table 19 summarises federal guidelines for new plants.

2.3.3 Solid Waste Disposal. The federal government exercises no direct regulatory control over solid waste disposal in the pulp and paper industry, but most provinces have and enforce relevant regulations. However, since solid waste disposal often generates contaminated leachates and occasionally causes air pollution problems, there is often indirect federal control over solid waste disposal practices.

2.3.4 Hazardous Chemicals. Various regulations have been enacted by the federal authorities to control or prohibit the use of hazardous chemicals. These effectively eliminate them as a problem in the pulp and paper industry, and they are not discussed in this manual, except with respect to disposal of certain previously stocked materials which are now prohibited or severely restricted.

The Pesticide Act and the regulations of Agriculture Canada and of the Food and Drug Directorate impose a number of restrictions on the chemicals that can be sold and used in Canada. Materials such as biocides used in the industry are normally licensed by one or more of the above bodies. Since much of the paper produced in Canada is sold in the U.S., many companies ensure that all potentially toxic materials used are also approved by the U.S. Food and Drug Administration.

2.4 Principal Pulp and Paper Production Processes

2.4.1 General. The first step in the manufacture of paper consists essentially of separating the wood into fibres by mechanical or chemical processes and removing impurities. The intermediate product is known as pulp, and is often exported by Canadian mills. Paper is made by blending suitable grades of pulp with non-fibrous additives and then forming a sheet with characteristics suitable for the intended use.

The fibres are usually bleached to some degree for printing grades of paper and normally unbleached for other uses such as packaging and building papers.

Readers are referred to the glossary for definitions of unfamiliar technical terms.

2.4.2 Wood Preparation. Most of the production processes commence by removal of the bark from the logs since it is essentially nonfibrous and is detrimental to many paper characteristics. In the past, much of this bark was dumped in a landfill or an adjacent river; the most common current practice is to burn the bark to resolve the disposal problem and generate steam.

Traditionally, the wood preparation area of a mill used large quantities of water and discharged an effluent with high suspended solids and BOD content. Many mills now avoid this problem by using dry processes in the wood preparation area.

In some modern installations, particularly in British Columbia, the log is transformed into lumber by machinery which also cuts all waste wood into chips ready for transformation into pulp. Due to the larger diameter trees and intensive lumber industry, wood preparation practices in British Columbia are more sawmill-oriented than in the east. Some pulp and paper mills use only purchased sawmill chips, so have no wood preparation plant.

2.4.3 Pulping and Bleaching. The two main types of pulping are chemical and mechanical. In the first, the chips are separated into fibres by cooking in a pressure vessel with chemicals and steam. The predominant chemical process is kraft, also known as sulphate, which produces a strong, dark coloured pulp suitable for the manufacture of many types of paper. The other principal chemical process, sulphite, produces a weaker, but less coloured pulp particularly suitable for printing grades of paper, often with little bleaching.

In kraft pulping, the nonfibrous components of the wood, which are not transformed into pulp, are recovered and recycled along with most of the cooking chemicals. Recovery of the nonfibrous waste from sulphite pulping is rarely practiced due to a combination of economic and technical factors. This creates a problem in controlling BOD discharges in many cases.

Mechanical pulp is produced either by grinding the logs into separate fibres with rotating stones, or by forcing chips between grooved rotating steel plates in refiners. Mechanical pulping transforms over 90% of the debarked wood into useful pulp, whereas most chemical pulping operations can convert under 60% of the wood into pulp.

In the mechanical pulping processes, the soluble material separated from the wood is discharged to sewer and represents a significant quantity of BOD and toxicity in some cases, although significantly less than in the case of a sulphite mill without a chemical recovery system.

In all the above-mentioned processes, the pulp is produced as a slurry in water after removal of spent cooking chemicals and dissolved wood organics. It is then dried for sale as market pulp to paper mills, or further treated by refining, cleaning and addition of other pulps and chemicals and made into paper on-site. Most of the pulp destined for printing uses is bleached or, in some cases, semi-bleached. Traditionally, newsprint has not been bleached, but many newsprint mills now practice a limited form of bleaching commonly known as brightening.

Bleaching chemical pulps is generally complex and uses several chlorine-based chemicals. About 7% of the pulp is solubilized and discharged to sewer, contributing most of the colour and much of the BOD and toxicity in bleached pulp mill wastes. Bleaching mechanical pulp is simpler and produces relatively little effluent.

The principal operations of a hypothetical composite mill are shown in Figure 3. This is necessarily simplified and omits most of the hundred or so recycle loops that such a mill would have.

All the above processes and their variations are described in detail in the subsequent sections of this manual.

2.4.4 **Principal Final Products.** Until the mid-1970s, newsprint was made from a mixture of about 25% sulphite pulp and 75% groundwood pulp. Recently, the trend has been to replace the groundwood with thermomechanical pulp (produced under pressure in refiners) and to reduce the sulphite pulp component or eliminate it altogether. It is technically feasible to replace the sulphite component with kraft, but this is economically feasible only in certain cases.

Bleached kraft pulp is usually sold to paper mills, mostly on the export market, but a few Canadian bleached kraft mills are integrated with paper mills and produce fine papers, using primarily their own pulp with the addition of small amounts of other pulps and the appropriate additives.

Unbleached kraft pulp may be sold but is most often made into linerboard or other grades of packaging papers on-site.

The larger sulphite mills generally sell their production on the market whereas the smaller ones are usually integrated with paper mills and furnish only the on-site paper machines, mostly producing newsprint and similar grades of paper.

2.4.5 **Effluent and Atmospheric Emission Sources.** Historically, enormous quantities of water were used in pulp and paper mills for the transportation of wood within the mill, for power generation, and for the processing of wood fibre into pulp or paper. Water was used on a "once-through" basis and the resulting large losses of chemicals, fibre and heat were not of major importance in an era of inexpensive wood and energy and little

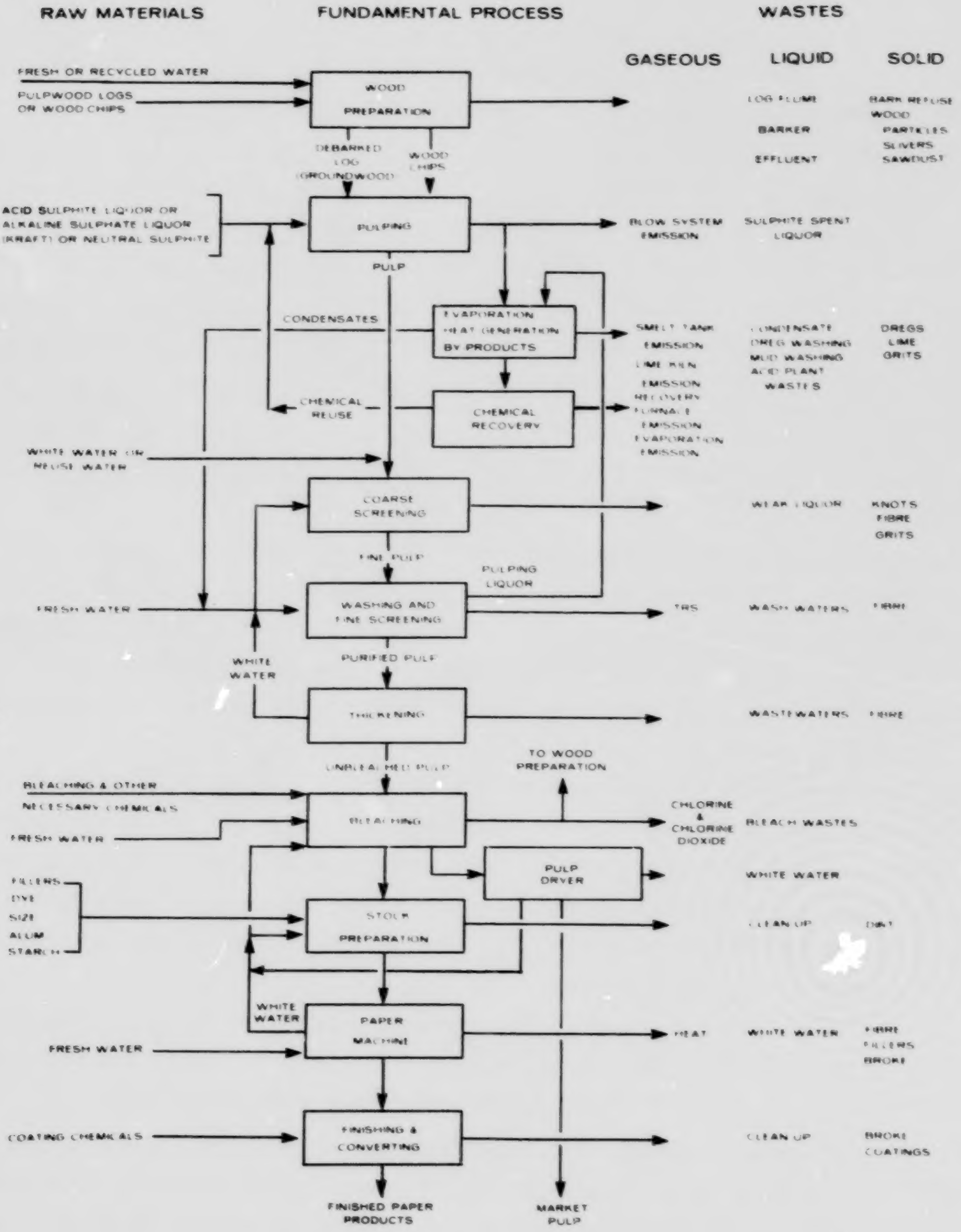
RAW MATERIALS
FUNDAMENTAL PROCESS
WASTES
GASEOUS
LIQUID
SOLID
FRESH OR RECYCLED WATER
PULPWOOD LOGS OR WOOD CHIPS
WOOD PREPARATION
LOG FLUME
BARKER
EFFLUENT
BARK REFUSE
WOOD
PARTICLES
SLIVERS
SAWDUST
DEBARKED LOG (GROUNDWOOD)
WOOD CHIPS
ACID SULPHITE LIQUOR OR ALKALINE SULPHATE LIQUOR (KRAFT) OR NEUTRAL SULPHITE
PULPING
BLOW SYSTEM EMISSION
SULPHITE SPENT LIQUOR
PULP
CONDENSATES
EVAPORATION HEAT GENERATION BY PRODUCTS
SMELT TANK EMISSION
LIME KILN EMISSION
RECOVERY FURNACE EMISSION
EVAPORATION EMISSION
CONDENSATE
DREG WASHING
MUD WASHING
ACID PLANT WASTES
DREGS
LIME
GRITS
CHEMICAL REUSE
CHEMICAL RECOVERY
WHITE WATER OR REUSE WATER
COARSE SCREENING
WEAK LIQUOR
KNOTS
FIBRE
GRITS
FINE PULP
PULPING LIQUOR
FRESH WATER
WASHING AND FINE SCREENING
TRS
WASH WATERS
FIBRE
WHITE WATER
PURIFIED PULP
THICKENING
WASTEWATERS
FIBRE
UNBLEACHED PULP
TO WOOD PREPARATION
BLEACHING & OTHER NECESSARY CHEMICALS
FRESH WATER
BLEACHING
CHLORINE & CHLORINE DIOXIDE
BLEACH WASTES
PULP DRYER
WHITE WATER
FILLERS
DYE
SIZE
ALUM
STARCH
STOCK PREPARATION
CLEAN UP
DIRT
WHITE WATER
PAPER MACHINE
FRESH WATER
HEAT
WHITE WATER
FIBRE
FILLERS
BROKE
COATING CHEMICALS
FINISHING & CONVERTING
CLEAN UP
BROKE
COATINGS
FINISHED PAPER PRODUCTS
MARKET PULP

FIGURE 3 SIMPLIFIED DIAGRAM OF TYPICAL PULP AND PAPER PROCESSES

competition. Pulp and paper manufacture still uses large volumes of water in most stages of processing, but extensive reuse and recycle of water within the departments, and the segregation of relatively clean used water from more contaminated water and condensates is now normal practice. This has enabled mills to dramatically reduce their requirements for fresh water, with a corresponding reduction of volumes of effluents requiring treatment. A dramatic reduction of fibre, chemical and heat loss, and of contamination of receiving waters has been achieved simultaneously.

In the course of pulp and paper manufacture, wastes are generated to a greater or lesser extent depending on the process. Fundamentally, this is a question of yield. Yield is usually defined as the amount of pulp or paper leaving as product divided by the amount of wood entering. The yield is always less than 100%. Lower yields signify high cellulose content in the product, as is the case for chemical pulps. Higher yields such as those from groundwood or thermomechanical processes contain substantial proportions of lignin. The yields of processes currently used range from about 30% to 95%.

The difference between the process yield and 100% represents the wastes from the process which must be disposed of either directly or indirectly. Most of these wastes are in the form of suspended or dissolved solids such as cooking, bleaching and other liquors containing fibre, wood-based organic compounds, and pulping and paper-making chemicals. A small proportion of the losses are gases and vapours from processes such as cooking, evaporation and chemical recovery processes, or solid wastes such as chip rejects, sand, dirt, sludges and foreign solid matter.

Further detail is provided in Sections 4 through 12 in which mill operations are discussed department by department. Individual sources can be summarised as follows.

Up to 15% of the weight of wood, in the form of bark, must be removed and either used as fuel or disposed of to landfill. The wet debarking process creates a substantial proportion of the effluent in many mills.

A small proportion, normally under 1%, of the material entering any of the above processes is relatively inert and inherently waste and must be removed from the product to satisfy the customers' requirements. This waste consists of sand and related materials, and contributes to suspended solids in mill effluents.

A further proportion, from one-twentieth to about 1.3 times the weight of the product, consists of soluble wood organics which are separated from the raw wood in the pulping process. This material is the principal source of the BOD and toxicity in mill effluents.

In the case of kraft mills, this organic material is virtually all recovered and burned in the recovery furnace along with the spent cooking chemicals. The pollutant discharges from this process consist of losses from the complex pulping and recovery cycles, which are due to the practical, technical and economic difficulties in achieving 100% efficient operation of the equipment, and usually represent a few percent of the total amount of material being processed.

Similar remarks apply in the case of low-yield sulphite mills, although technological difficulties limit recovery system efficiencies to levels lower than those common in kraft pulping. As the pulping yield rises, the generation of waste organics drops, but the difficulty of achieving efficient recovery and recycle of these organics rises substantially. Most low-yield sulphite mills remaining in Canada are quite large and practice some form of chemical recovery, either through a traditional process or by the manufacture of by-products. This results in the medium- and high-yield sulphite mills often having greater BOD discharges to sewer than the low-yield mills.

Although the relationship between BOD and organic material discharged is complicated and nonlinear, it is generally true that BOD rises roughly in proportion to the organic content in pulp industry wastes.

In principle, there need be no atmospheric discharges from chemical pulping recovery processes other than harmless combustion products such as water vapour and carbon dioxide. However, the practical limitations of the available equipment cause emissions of malodourous gases, particulates and, in some cases, significant amounts of sulphur dioxide.

In the mechanical pulping process it is not practical, with current technology, to recover and recycle the organics removed from the wood.

The bleaching of chemical pulp requires the removal of residual lignin from the raw unbleached pulp, normally using chlorine or chlorine compounds. The organics removed could, in principle, be recovered and incinerated along with the organics removed in the pulping process. However, due to the contamination with chlorides, this is practiced in only one mill at the time of writing. These organics, therefore, become an important source of BOD and also of toxicity in the process effluents.

Some of the chemicals used in manufacturing pulp remain in the product or are incinerated. However, in addition to the yield loss, most of the bleaching chemicals and a proportion of the other chemicals used in the process must be discharged, mostly as dissolved solids in the effluent.

In all variations of the pulping and papermaking processes it is necessary to transport large quantities of pulp as a dilute suspension in water, and to dilute and re-thicken this suspension several times to create the operating conditions appropriate to each type of equipment. This in turn necessitates the recycle of large volumes of water containing very small concentrations of fibre (under 0.1%), normally known as white water although it may be very dark brown in some cases. Practical equipment limitations, overflows and leaks of this material contribute a substantial proportion of the suspended solids in the effluents from most mills. The recycle efficiency of white water has improved steadily over the past 50 years and continues to improve, thus reducing suspended solids losses.

In addition to the continuous effluent discharges and atmospheric emissions discussed above, significant discharges occur due to unforeseen equipment failures and human error. As recycle technology has improved and some inherently polluting processes have been phased out, the relative significance of these accidental discharges has increased; they often represent over a third of the total suspended solids and BOD discharges from a mill. In many cases, particularly with respect to atmospheric emissions, short-term increases in amounts discharged can be spectacular and cause far more adverse public reaction and environmental damage than an emission which frequently or even continuously exceeds regulations by a modest margin. It has been suggested that, in many cases, the resources available for environmental protection would be best used to reduce the frequency and severity of accidental discharges rather than on attempts to reduce continuous emissions to extremely low levels.

3 HISTORICAL DEVELOPMENT

Paper can be defined as any kind of matted or felted sheets of fibres formed on a wire screen from an aqueous suspension. The ancient Egyptians of Alexandria used the pith of the papyrus reed to make a usable sheet, and the word "paper" is derived from the name of this plant. Fibrous layers were removed, planed side by side at right angles, pounded, dampened and pressed. Complete defiberizing was not part of the process. Papyrus sheets were the most widely used form of writing material in ancient times. Documents date back to 3 600 B.C.

Paper as we know it today originated in China about 100 A.D. T'sai Lun, called the father of papermaking, first made it from the inner bark of the mulberry bush. He found that a mascerated fibrous suspension, after being filtered through a fine screen and dried, gave a suitable sheet for writing and drawing. The bast fibres of hemp and flax were used at first but were later replaced by fibre from cotton and linen rags as quality and skill improved. The addition of the mucilages and starches of plants as well as animal glue and vegetable gums was found to impart strength and smoothness, and to improve writing quality. Cotton and linen rags are still used today for high-grade bond, bank note and record paper, or whenever permanency is important. The art of papermaking reached Europe around the twelfth century. By 1390, a number of paper plants existed in Spain, Italy, France, and Germany.

The following events, listed in chronological order will give the reader a thumb-nail sketch of major developments up to the present day.

1495 The publication of the Gutenberg Bible marked the beginning of book printing and the consequent increased demand for paper.

1680 The invention of the Hollander beater, a mechanical method for mascerating or defiberizing large batches of raw fibrous material.

1784 Discovery of chlorine by the Swedish chemist Scheele. It was quickly recognized for its bleaching ability on paper stock. Its initial use resulted in inferior paper and discredit due to improper use.

1798 Invention of a continuous paper machine by Nicholas Robert in France. Bankruptcy set in before he could complete his invention.

1800 The development of vat sizing with rosin and alum. Previous sizing was done with animal glue and vegetable gums and was expensive and tedious. Rosin and alum are still used today and impart wet strength, ink hold-out, and improved printability.

1807 A patent was issued to Henry and Sealy Fourdrinier for an "Improved Paper Machine". The new possibility of greater paper production sparked a vigorous search for large quantities of new raw materials as cotton and linen rags were scarce.

1809 The invention of the cylinder paper machine by the English papermaker John Dickinson.

1844 Groundwood or mechanical pulp was invented by Keller in Germany, but did not reach commercial use until 1870 because of its poor strength properties.

1854 The beginning of chemical wood pulping. Watt and Burgess in England made "soda pulp" by boiling wood in caustic alkali at high temperature.

1897 Paper machine speed had reached 150m/min.

1894 First pulp and paper mill in British Columbia started up at Alberni on Vancouver Island. Six months later it closed.

1900 As the 20th century began, papermaking in Canada was still a fairly small industry, largely serving the Canadian market.

1907 First kraft pulp produced in North America at East Angus, Quebec, by Brompton Pulp and Paper Company.

1912 First forest fire protection association formed in the St. Maurice Valley of Quebec.

1913 U.S. forests could not fill all of the increased needs for wood caused by the rapid rise in paper requirements in that country. The U.S. government removed the newsprint tariff altogether, which gave stimulus to the growth of the newsprint industry in Canada.

1913 Forest Products Laboratories, forerunner of the Pulp and Paper Research Institute of Canada, was established in Montreal.

1913 The Canadian Pulp and Paper Association was formed.

1913 First sulphate mill in North America to be built with a recovery system for pulping chemicals.

1918 Canada's pulp and paper output exceeded $100 million for the first time. This was more than 10 times higher than at the turn of the century. Canada became the world's largest exporter of pulp and paper.

1920 Machine speeds of 300 m/min became feasible.

1920-29	Expansion of the Canadian industry continued and the great papermaking centres of northwestern Ontario, and Quebec's St. Maurice Valley, Ottawa Valley and Lake St. Jean regions experienced rapid growth. In 1926, Canada's newsprint production exceeded that of the U.S. for the first time; thereafter the gap widened.
1928	The Pulp and Paper Research Institute of Canada was established.
1930-33	Production of pulp and paper in Canada declined by one-third in volume and one-half in value as the great depression struck. The effects were devastating, especially for newsprint producers.
1933-34	A system for recovering kraft pulping chemicals from black liquor was demonstrated by the Canadian, George Tomlinson, at Windsor, Quebec.
1935	Demand began to improve and rehabilitation of the industry began.
1935-45	Mobilization of Canada's resources during World War II affected the industry in various ways. During the early years, production increased substantially and additional manufacturing facilities were required to serve the exceptional needs that developed. Later, output was restricted somewhat as more urgent national needs for men, materials and electric power took priority.
1946	The companies adjusted to peace time operation. Output rose sharply, and by 1950 exceeded 7 million short tons, worth $950 million. Some products, especially newsprint, were in short supply for several years, as the post war economic boom unfolded.
1946	Two Canadians, Howard Rapson and Morris Wayman, designed the first plant to manufacture chlorine dioxide as a bleaching chemical at Temiskaming, Quebec. It became possible to bleach kraft pulp to whiteness hitherto thought impossible without impairing its strength. This helped to set the stage for a huge expansion of bleached kraft production.
1955	The first continuous kraft digester in Canada.
1966-67	After 160 years, an alternative to the Fourdrinier paper machine appeared in the twin-wire former, where the fibres are formed into a sheet between two travelling screens.
1960-69	A large expansion of the Canadian industry occurred. New mills were built in every region of Canada, particularly in British Columbia.
1966	First major effluent treatment system was installed for pulp mill wastes.

The early 1970s were marked by construction of additional mills and the commercialisation of the thermomechanical (TMP) process.

The late 1970s were marked by heavy investments in modernisation of older installations, and the emergence of TMP, but few new mills were built. "Low-odour" recovery boilers became the standard for new installations. Provincial and federal environmental regulatory authorities were formed and enacted a variety of regulations specific to the pulp and paper industry. Most mills spent substantial sums on environmental research and on installing environmental protection measures.

4 WOOD PREPARATION

4.1 Wood Supply

Major changes in the methods of wood harvesting have occurred in the past 10 years. Once a labour-intensive operation, the trend is toward mechanisation through the introduction of sophisticated hydraulic and mechanical equipment. The felling, delimbing, bucking, and skidding of wood to the roadside by machines has substantially increased productivity in this area, although a significant proportion of the wood is still cut by hand.

The three logging methods in use today are the:

- shortwood system,
- full tree system, and
- tree length log system.

The shortwood system, which is the most common, consists of felling, delimbing, cutting into lengths (usually either 1.3 or 2.5 metre logs), piling and/or transporting the wood to roadside. While this method still largely involves manual labour, more and more operations are being mechanised.

In the full tree system, the full tree is felled, topped and piled. Bundles are then hauled to the roadside for further processing or haulage to the mill. In the tree length log system, machines de-limb, top, sever the tree from its stump, and pile them in an orderly fashion for another machine to take them to the roadside. Various combinations of these methods are used according to terrain and local costs.

The conversion to mechanised logging involved large initial expenditures to develop machines for operation on rugged terrain and in extreme temperatures, and to develop the necessary facilities to maintain complex equipment at remote sites. However, reduced labour costs and the elimination of the need for large camp facilities were compensating factors. While mechanisation lowered production costs in the forests, it has made the pulp mill operations somewhat more difficult, since the wood delivered to the plant is now dirtier and unsorted, and more rotten wood is received.

During the 1970s the practice of cutting the better lumber from the log before chipping grew widespread and many small sawmills installed barking and chipping equipment so that sawmill chips now provide a higher proportion of wood supply than in the past. This transfers some of the solid waste disposal problem to the sawmill, and also increases the dirt entering the pulp mill system.

While most paper companies operate their own woodlands division, they also purchase wood from regional farmers and wood chips from local sawmill operators.

The traditional river driving of logs to the mill is used less today than in the past, although it is common for mills that were built for reception of wood this way to dump wood arriving by truck in the river close to the mill and reclaim it using the old equipment. This washes the logs and allows some storage and sorting with minimal equipment. It also causes some river pollution due to the bark removed by abrasion between logs.

On the west coast, much of the wood is transported as rafts of thousands of tonnes of logs tethered together and towed by tugs.

Newer mills usually receive all wood by truck and handle it by conveyors and mobile equipment. This approach generally requires more space than the traditional approach and may be impossible in older mills with space restrictions.

4.2 Wood Handling

On arrival at the mill, the wood is stored prior to use for a few days to several months. Many mills use flumes to collect wood from storage and convey it to the woodroom for debarking. Flumes require a large circulating flow of water which becomes contaminated by bark fines, organic leachate from the bark, sand and grit.

A degritter to remove heavy grit and a screen to remove the larger bark particles from the water are essential parts of any modern flume system. In some cases, the excess flume water is discharged to the mill sewer, but in most cases the flume water system is integrated with the debarking system; effluent disposal is combined with the latter.

Where the mill uses dry mechanical equipment for wood handling, there is essentially no effluent generated from the operation.

A substantial quantity of solid waste is attached to the logs that arrive in mill yards by truck; several hundred tonnes of soil, bark and broken wood have to be disposed of annually in these mills. This is normally dumped to landfill and, provided reasonable measures are taken, is not a significant environmental problem.

Mills that do not carry a substantial inventory of logs usually store several months' supply of chips in piles at the mill site. An overall wood handling, debarking and chipping system is depicted in Figure 4.

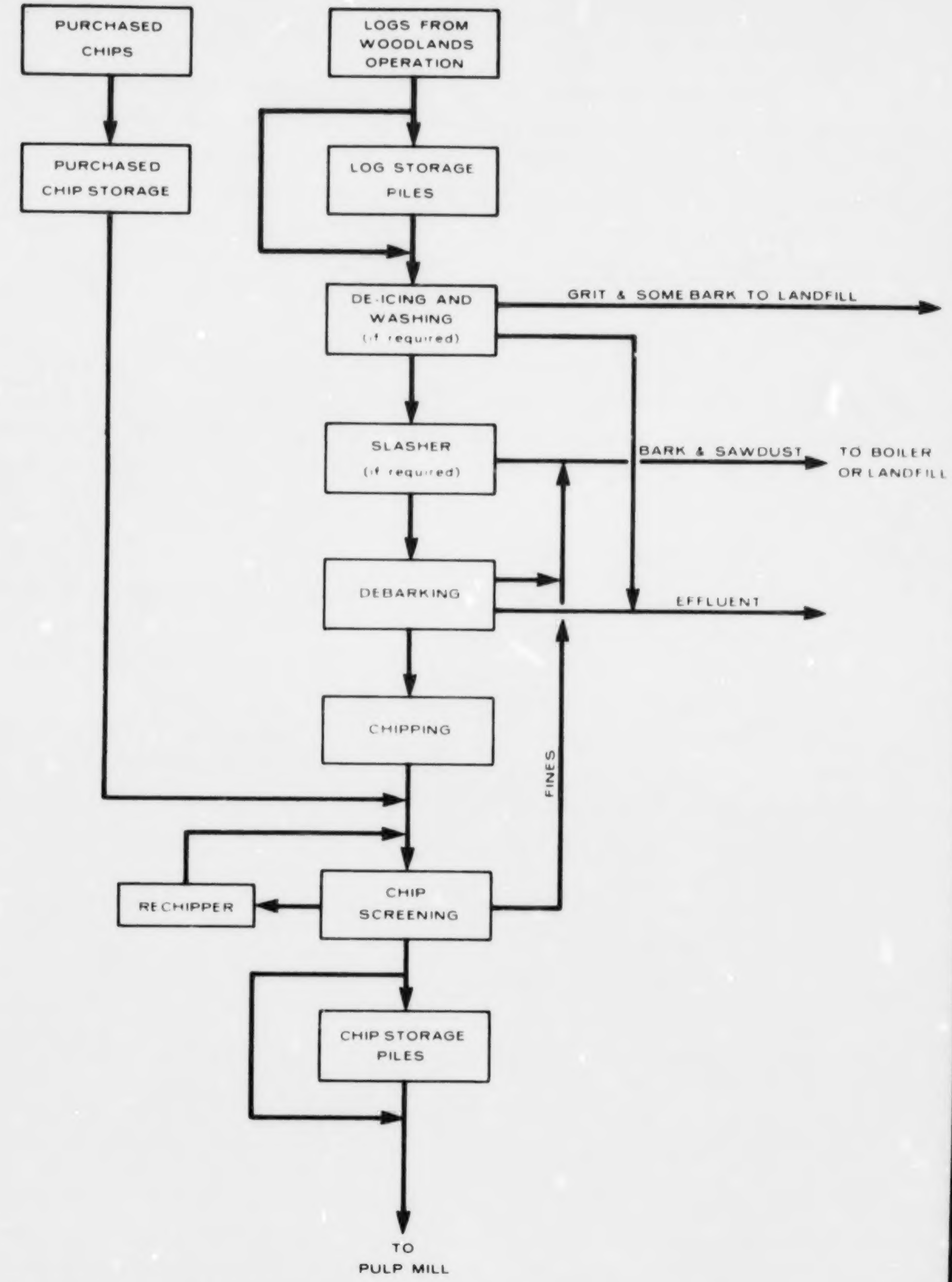
PURCHASED CHIPS
PURCHASED CHIP STORAGE
LOGS FROM WOODLANDS OPERATION
LOG STORAGE PILES
DE-ICING AND WASHING (if required)
GRIT & SOME BARK TO LANDFILL
SLASHER (if required)
BARK & SAWDUST
TO BOILER OR LANDFILL
DEBARKING
EFFLUENT
CHIPPING
FINES
RECHIPPER
CHIP SCREENING
CHIP STORAGE PILES
TO PULP MILL

FIGURE 4 WOOD PREPARATION FLOWSHEET

4.3 Debarking

The bark must be removed from the logs to ensure that the pulp is free of bark and dirt. The following equipment is in common use:

- wet drums,
- dry drums,
- hydraulic jets, and
- mechanical debarkers.

The barking drum is the most common form of debarking. A typical wet debarking drum is shown in Figure 5. Bark is removed from the logs by the friction created from the rotating drum action as the logs rub against each other.

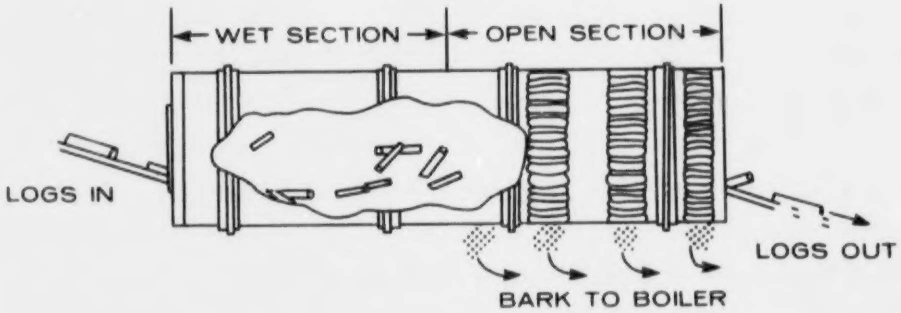

FIGURE 5 TYPICAL WET BARKING DRUM

The wet inlet section is of solid steel plate, while the open section on the right has slots in the drum to let the bark fall out. In dry barking, the drum will have the open section full length.

In wet drum barkers, water is added at the feed end to help loosen the bark and flush the loose particles out of the drum. The more recently installed wet debarkers often have a solid steel portion at the input end which is arranged to hold a pool of water to soak the logs. The remaining portion of the drum has slots to permit the removed bark to fall out while the log continues on through. The older drums usually have slotted openings for their full length. Bark from a wet system is generally collected in a water flume, or conveyors, passed through a dewatering system, and then through a bark press to the bark burning furnace. A wet barking recovery system layout is illustrated in Figure 6.

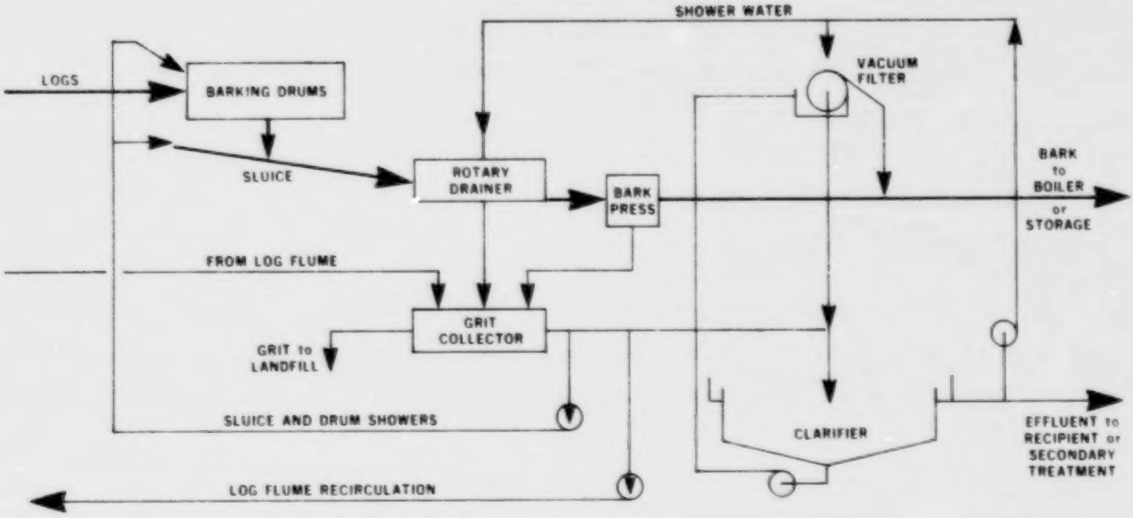
SHOWER WATER
VACUUM FILTER
LOGS
BARKING DRUMS
SLUICE
ROTARY DRAINER
BARK PRESS
BARK to BOILER or STORAGE
FROM LOG FLUME
GRIT COLLECTOR
GRIT to LANDFILL
SLUICE AND DRUM SHOWERS
CLARIFIER
EFFLUENT to RECIPIENT or SECONDARY TREATMENT
LOG FLUME RECIRCULATION

FIGURE 6 TYPICAL WET BARKING RECOVERY SYSTEM

In dry drum barkers, the entire length of the drum has slots for bark removal. The drums are longer and rotate much faster than wet drum barkers. The bark from dry drum barkers can be fired directly into bark burning furnaces.

Drum barkers create waste of up to about 5% of the wood input. The logs from this system usually have broomed ends which produce inferior wood chips for pulping. In long log debarking, the logs are debarked in one piece, passing through the drum parallel to each other.

Hydraulic jet barkers are most common on the west coast as they are not suitable for small logs or frozen wood. They are generally used with large size logs and operate by directing high-pressure (7 000 kPa or more) jets of water against the log to remove the bark. Bark removal is quite efficient, although the capital cost and energy requirements are high. Wood damage is small and wood loss is under 2%. The refuse from such a system is saturated with water and further treatment is required to recover the bark as a useable fuel.

Dry mechanical debarkers use rotating knives to strip the bark from the logs. Their use is mostly confined to small operations such as sawmills, although a few larger installations exist.

Wet wood handling and barking produce cleaner logs than dry barking because the water removes sand, grit, and bark fines. The wet process has, therefore, traditionally been preferred by mills using processes such as sulphite or mechanical pulping, which can tolerate little dirt. However, the cost of treating the woodroom effluent is high (typically a few million dollars capital) and almost all newer mills have chosen dry woodrooms and have installed efficient chip washing and pulp cleaning systems in the pulp mill to remove the dirt from the pulp. As well as avoiding the cost of treating woodroom effluent, dry barking provides the opportunity for increasing the generation of steam from hog-fuel.

4.4 Chipping

Stone groundwood mills use the debarked logs in unchipped form. For the other pulping processes, the log is reduced to wood chip fragments generally 12 to 18 mm in size. This permits rapid penetration of the cooking liquor into the wood during chemical pulping operations, and is also necessary for refiner mechanical pulping.

There are several different designs of chippers although the most common is the multiknife chipper. This unit consists of a series of knives attached to a rotating circular disc to which the logs are fed through an offset chute. Since off-size chips cause considerable problems in pulping, as well as creating high screenings, the production of uniform chips is very important. Blunt or damaged chippers will reduce pulp strength properties because of chemical degradation of the cellulose on pulping. Proper speed control and attention to the sharpness of the knives is necessary to minimise chip damage, fines production and slivers.

The elimination of fines and dust is critical in continuous pulping units; otherwise, they tend to clog the liquor circulation screens and fill the spaces between the chips, resulting in poor liquor circulation and complete blockage of the digester. As well as disrupting production, a blocked digester upsets the process and usually causes some black liquor spills to sewer. The acceptable chips are separated from sawdust and slivers by mechanical screening. The properly sized chips pass through the screen while oversize chips remain on the screen until rejected to a conveyor which carries them to a rechipper for size reduction. Many operations also carry out air blasting or further screening or washing of the chips to remove dust and undersized chips.

Undersized chips may be passed on to the pulp mill in some cases (usually when batch digesters are used) but are usually removed for use as fuel. Chipping does not generate any significant pollution.

4.5 Effluent Discharges

Completely dry wood handling and debarking systems usually have no process effluent. Wet systems typically use about 2 000 L/min water per drum; flumes require 20 000 to 150 000 L/min water. Internal recycle reduces the effluent flow to about 10 000 litres per oven dry tonne (ODt) wood processed. Some systems achieve effluent flows below 1 000 L/ODt wood through use of centrifugal cleaning systems for the recycled water. However, maintenance costs are high, due principally to the presence of sand and grit in the water combined with organic acids.

A typical wet woodroom system with reasonably effective bark recovery will discharge about 40 kg suspended solids per ODt wood processed. Much of this is organic and theoretically has a fuel value, but the difficulty of recovering and dewatering it limits recovery efficiency. If a woodroom effluent treatment clarifier, as shown in Figure 6, is installed, the suspended solids discharge will be about 3 kg/ODt wood.

BOD discharges vary widely; the values have rarely been documented, but may reach 8 kg per ODt wood processed. In interpreting woodroom effluent data, it is necessary to consider the contribution to BOD made by the use of a waste stream instead of water in the process. Bleach plant caustic extract and paper mill white water are often used and can raise the woodroom effluent BOD to 15 kg/t wood.

In view of the large circulating flows and reliance on the screening systems, wet woodrooms are always susceptible to accidental discharges to sewer due to equipment breakdowns. The high salt content of seawater-driven wood causes particular maintenance difficulties, tending to lower equipment reliability.

It is sometimes practical to convert older wet woodrooms to the dry process, although a complete rebuild of the bark drums, including lengthening, is usually required to maintain full production rates.

4.6 Disposal of Bark and Wood Waste

The bark removed from the wood represents a major disposal problem at older mills; however, world increases in oil prices have made bark burning boilers economically attractive for most mills.

Bark residue has been burned for a number of years in specially designed bark burning furnaces although many were thermally inefficient. Bark represents an inexpensive, low quality fuel source; depending on its moisture content, it can be burned alone or in combination with oil, coal or gas to generate steam. Bark burning is most economical when used with dry debarking operations.

Bark from a wet debarking process that is to be burned must first be dewatered. Presses are used to reach the highest dry content feasible (about 50%); the pressate (the water removed by the press) is returned to the woodroom water system. Although bark has been burned in the past at relatively high moisture contents, this required the use of auxiliary fuel, normally oil or gas. Today's fuel costs require efficient pressing of all bark that has to be burned. The technology of bark pressing is straightforward, but the equipment is expensive (typically about one million dollars for a press installation) and requires extensive maintenance.

A few installations now use bark drying equipment to lower the moisture content to as low as 10%.

Whether dry or wet barking is used, an efficient bark burning operation requires at least several days capacity of bark storage. This must be designed and operated to control the discharge of leachates, which create significant amounts of effluent in some cases. Some mills purchase bark and other wood residues externally for use as fuel, adding considerably to the storage space requirements and potential leachate problems.

Fluidized bed combustion systems have been introduced. Although effective as bark disposal devices, their thermal efficiency is limited; they have been used primarily to produce hot water by direct scrubbing of the hot flue gases. However, hot water can usually be produced more cheaply from other low grade heat sources in the mill; very few such installations therefore exist. Air pollution is minimal.

The composting of bark has had little success except in some of the warmer climates because of the bark's resistance to biodegradation. Some paper companies that also manufacture building board can produce an acceptable building board containing up to 25% bark. The use of bark and wood waste residue in this application is very limited.

4.7 Atmospheric Emissions

Atmospheric emissions from the wood preparation areas consist of small quantities of fugitive sawdust from mechanical handling systems, particularly pneumatic conveyors. This is merely a local cleanup nuisance in most cases, since essentially all the material falls within the plant boundaries except in a few cases where there are public roads or residences within approximately a few hundred metres.

5 PULPING

The pulping department receives the wood from the wood preparation department described in Section 4 and transforms it into pulp. It is commonly known as the pulp mill, which can be confusing since this term may also be used to describe complete pulp producing complexes including bleaching, power plants etc., or it may refer to various combinations of departments which include the actual pulp production equipment and some of the related departments. In this section, the term pulp mill refers to the actual pulping device (digester, grinder or refiner) and its immediate accessories, including the pulp washing system, where applicable.

The basic objective in pulping is to loosen and separate the individual fibres from each other as they exist in wood. Once softened and separated, these fibres are in a much more adaptable state for papermaking operations. Pulping is accomplished by the application of mechanical or chemical energy, or both, to the wood.

Simplistically, the wood fed to the pulp mill can be considered to contain about 45% cellulosic fibre, 20-30% lignin, 5% extractives, and about 25% hemicellulose. Chemical pulping methods remove most of the non-fibrous material whereas mechanical processes allow most of the lignin and much of the hemicellulose to remain in the fibre. All the material removed has high BOD and some of it is toxic to fish.

The yield, defined as the weight of pulp produced from unit weight of oven dry wood, varies widely for the different processes. There is also some range in yields for each process, depending on raw wood species, product quality required, and the technology of the production process.

In systems where the spent pulping chemicals and the soluble material separated from the wood are not recovered, the yield is the key process parameter which affects effluent quality. The quantity of organic material released in a pulping process is inversely proportional to the yield, so that a system operating with a yield of 90% discharges twice as much organic material as one operating at 95% yield. The BOD discharged is roughly proportional to organic discharge for any one type of process and within the practical range of yields. In the case of systems where the spent liquors are recovered, the effluent quality is more dependent on the efficiency of the recovery process than on the pulping yield. Typical yields of the principal processes are presented in Table 3.

Wood chemistry is discussed in greater detail in Appendix C. Table 4 summarises some salient properties of pulps used in newsprint and similar paper grades.

TABLE 3 TYPICAL PULP YIELDS

Unbleached Kraft	50-55%
Bleached Kraft	43-48%
Dissolving Sulphite	33-40%
Low Yield Sulphite	46-55%
Medium Yield Sulphite	55-65%
High Yield Sulphite	65-80%
Chemi-thermomechanical Pulp (CTMP)	80-90%
Thermomechanical Pulp (TMP)	91-95%
Stone Groundwood	94-96%

TABLE 4 TYPICAL NEWSPRINT PULP AND EFFLUENT CHARACTERISTICS[a]

	SGW[b]	PGW	RMP	TMP	CTMP	HYS	SBK
Freeness (mL CSF)	100	100	100	100	350	500	500
Shive Content (%)	1.6	1.4	1.2	0.4	0.3	0.3	
Bauer McNett +30 (%)	15	23	25	37	40	-	86
Bauer McNett 30-200 (%)	55	55	52	39	35	-	12
Bauer McNett -200 (%)	30	22	23	24	25	-	645
Breaking Length (m)	3 000	3 600	3 600	3 900	5 000	6 000	10 000
Tear Index (mN•M^2/g)	3.5	4.2	6.5	8	-	-	10.6
Sulphur Dioxide[c] (%)	0	0	0	0	2.5	5	N/A
Specific Energy (GJ/t)	5	5	7	7	5	2.7	
Yield[d] (%)	96	96	95	93	88	80	50
BOD kg/t	7-15	10-15	10-25	10-35	70	130	250[e]

[a] Data is indicative only. It is based on several sources, using different wood species.

[b] SGW - Conventional Stone Groundwood
PGW - Pressurised Stone Groundwood
RMP - Refiner Mechanical Pulp
TMP - Thermomechanical Pulp
CTMP - Chemi-thermomechanical Pulp
HYS - High Yield Sulphite
SBK - Semi-Bleached Kraft Pulp

[c] Typical quantities of cooking chemicals used.

[d] Yield data over 90% must be considered very approximate due to the lack of standardisation of measuring techniques.

[e] BOD prior to chemical recovery. A normal figure after recovery would be about 20 kg/t.

5.1 Mechanical Pulping

Mechanical pulping can produce pulps at a range of yields above 80%. The key process characteristic which determines the pulp quality for a given wood furnish is the specific energy input (GJ/tonne pulp) in the defibering operation, noting that higher operating pressures, and therefore higher energy inputs, are required for the higher quality pulps.

5.1.1 Stone and Pressurized Groundwood Pulp. The earliest form of mechanical pulping was that of stone groundwood (SGW). In this process, logs are forced into contact with a revolving grindstone in the presence of water, as illustrated in Figure 7. A typical SGW system flowsheet is shown in Figure 8.

In the grinding operation, the wood is reduced to mascerated fibres. The water applied cools, cleans, and lubricates the stone and acts as a medium for conveying the pulp away from the stone. Factors affecting groundwood pulp quality include wood species, source, age and moisture content of wood, as well as the condition of pulp stone surfaces, stone speed, operating pressure, and grinding temperature. Spruce, balsam fir, jack pine, western hemlock, poplar, and assorted hardwoods are most commonly used. Groundwood made from black spruce is bright and strong, while that from jack pine with its higher pitch content is darker and inferior in papermaking qualities. Poplar groundwood has very low strength but gives a much softer paper with good ink absorbency.

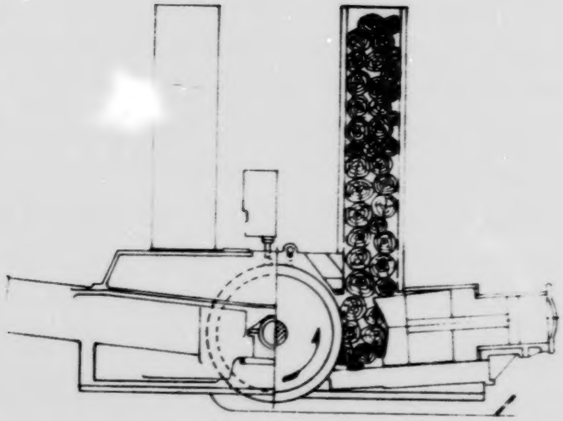

FIGURE 7 HYDRAULIC MAGAZINE GRINDER

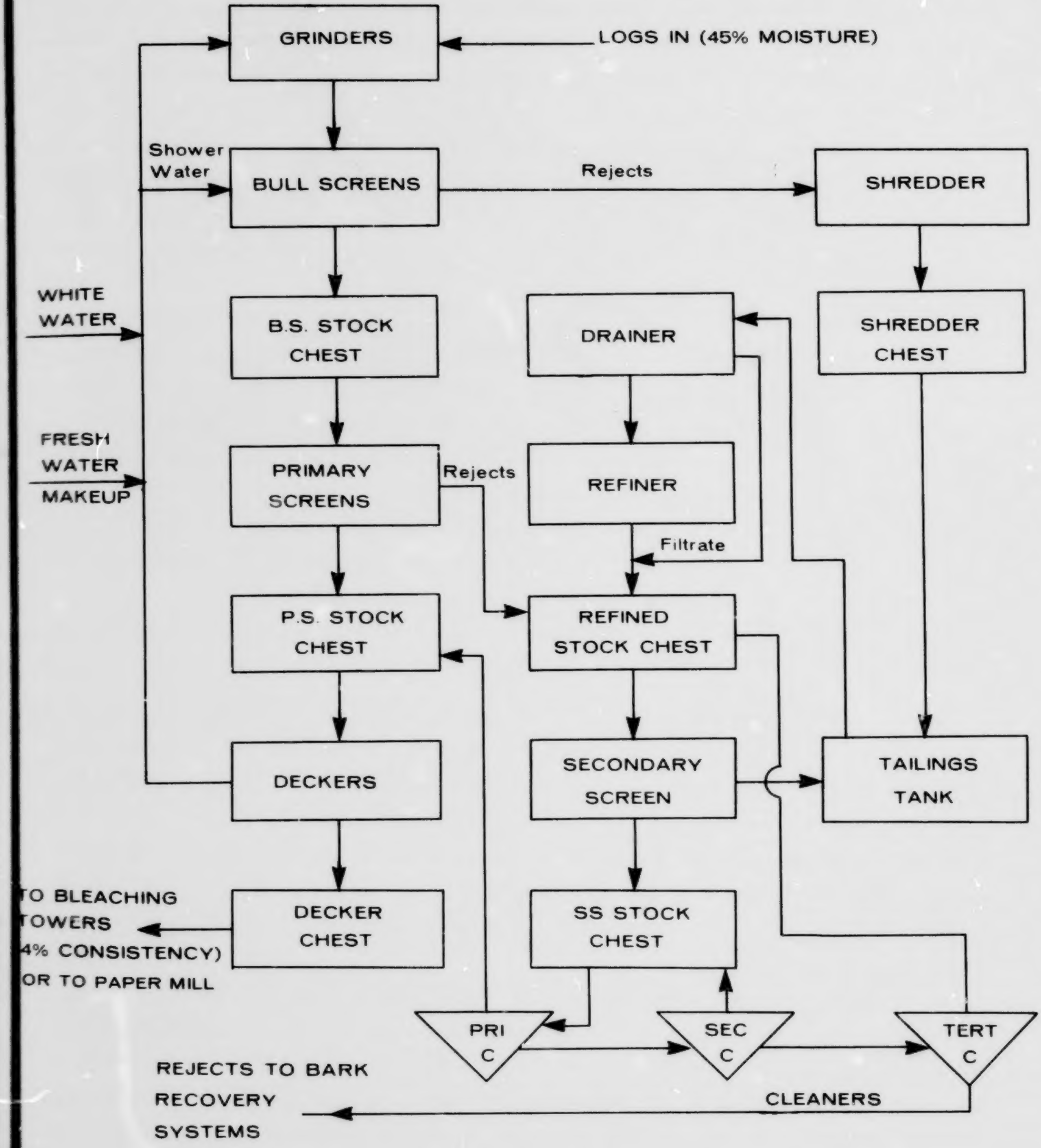
GRINDERS
LOGS IN (45% MOISTURE)
Shower Water
BULL SCREENS
Rejects
SHREDDER
WHITE WATER
B.S. STOCK CHEST
DRAINER
SHREDDER CHEST
FRESH WATER MAKEUP
PRIMARY SCREENS
Rejects
REFINER
Filtrate
P.S. STOCK CHEST
REFINED STOCK CHEST
DECKERS
SECONDARY SCREEN
TAILINGS TANK
TO BLEACHING TOWERS
4% CONSISTENCY)
OR TO PAPER MILL
DECKER CHEST
SS STOCK CHEST
PRI C
SEC C
TERT C
REJECTS TO BARK RECOVERY SYSTEMS
CLEANERS

FIGURE 8 TYPICAL GROUNDWOOD SYSTEM

Groundwood pulp contains slivers of wood up to about a metre long; these are removed by a coarse screen known as the bull-screen before the pulp is transferred to the screen room for further processing. Bull screen rejects are shredded and recovered in the reject refiner system described in Section 6. Most Canadian groundwood mills were built in the days before bull screen reject recovery was practiced; the locations where these recovery systems have had to be installed often lead to maintenance difficulties. Failure to recover bull screen rejects from the primary effluent can cause serious operating difficulties in any clarifiers downstream, or excessive suspended solids discharges if there is no primary treatment system.

Hardwoods ground in the conventional manner produce a short-fibred, weak pulp and may be subjected to chemical pre-treatment before grinding. This is known as the chemigroundwood process. The pre-treatment consists of soaking the log in a sodium sulphite and sodium bicarbonate liquor under elevated pressure and temperature. Pulp yields are slightly below those for conventional groundwood and are normally in the 85-90% range. Very little use has been made of this process in Canada.

The pressurised groundwood process (PGW) recently introduced to North America is a modification of the traditional stone groundwood process. The grinder is constructed as a pressure vessel where the grinding process occurs at a slightly elevated pressure. The pulp properties fall between those of TMP and conventional stone groundwood pulp.

5.1.2 **Refiner Mechanical Pulp.** A variation in mechanical pulp manufacture, refiner mechanical pulp (RMP), also commonly known as refiner groundwood, was introduced in the late 1950s. Wood chips are reduced to pulp by passing through double or single revolving disc refiners followed by the use of centrifugal cleaners for fibre classification. For certain applications, pre-treatment of the chips before refining is beneficial to the pulp produced. A typical double disc refiner is shown in Figure 9; a cutaway sketch appears in Figure 27. The pulp produced is stronger than stone groundwood pulp and is superior to it for most purposes.

An important advantage of the RMP process over the traditional stone groundwood is the ability to use chips, including those from sawmill cut-offs, whereas the stone process requires solid logs, normally 1.2 m long. The development of disc refiners has also made it possible to use sawmill wastes such as sawdust and shavings. The pulp quality obtained by refining sawdust is inferior to that from chip refining, but may be of comparable quality to that of stone groundwood.

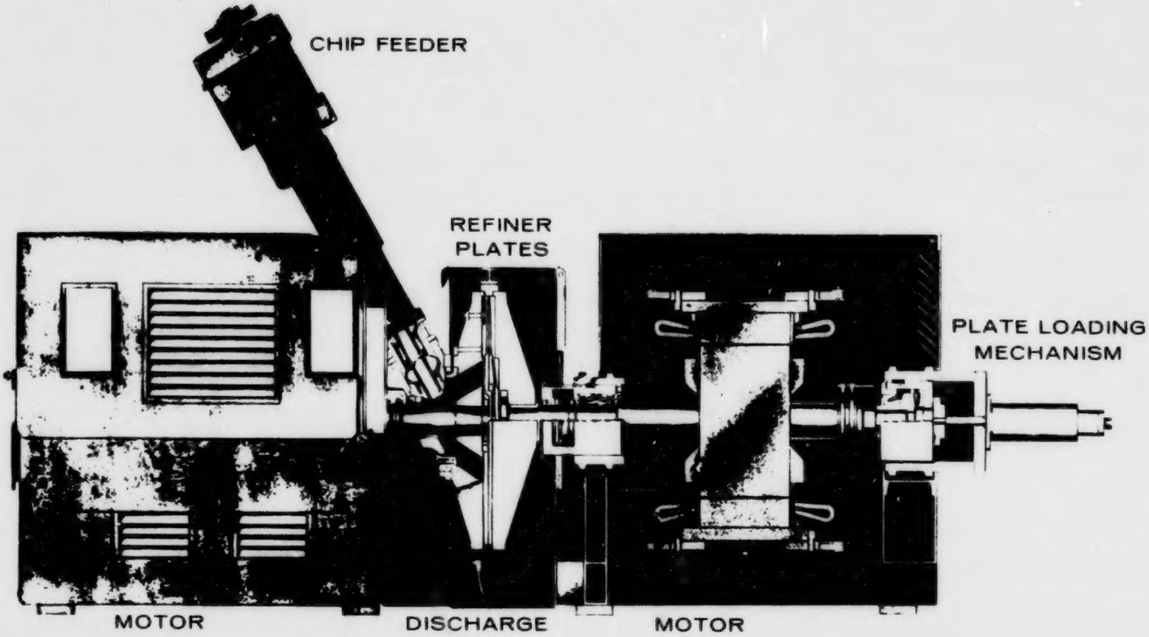

FIGURE 9 DOUBLE DISC REFINER

The refiner mechanical pulp process has proven to require more power than originally foreseen; it has largely been superceded by thermomechanical pulping.

5.1.3 **Thermomechanical Pulp.** Most of the mechanical pulping capacity installed in Canada since 1973 has been thermomechanical pulp, commonly known as TMP. In this process, the chips are softened by steam under pressure in a presteaming vessel, without chemicals, and then defibred in a disc refiner under pressure. The raw pulp is then further refined in a second stage refiner before passing on to screening and cleaning. The presteaming treatment normally lasts about three minutes at a pressure of about 150 to 200 kPa.

The yield is somewhat lower than groundwood, but pulp strength and runability on the paper machine are much better. The energy input is higher than for the stone groundwood process, although this can be partially offset by the fact that up to about 80% of the energy input may be recovered as low pressure steam suitable for use in the paper machine. Such heat recovery systems are now operating in several mills and some are under construction in Canada. A typical process flowsheet for a single TMP line is shown in Figure 10.

Since the steel plates in the refiners are operating at high speed a fraction of a millimetre apart, it is essential to minimise the entry of sand, grit and tramp metal to

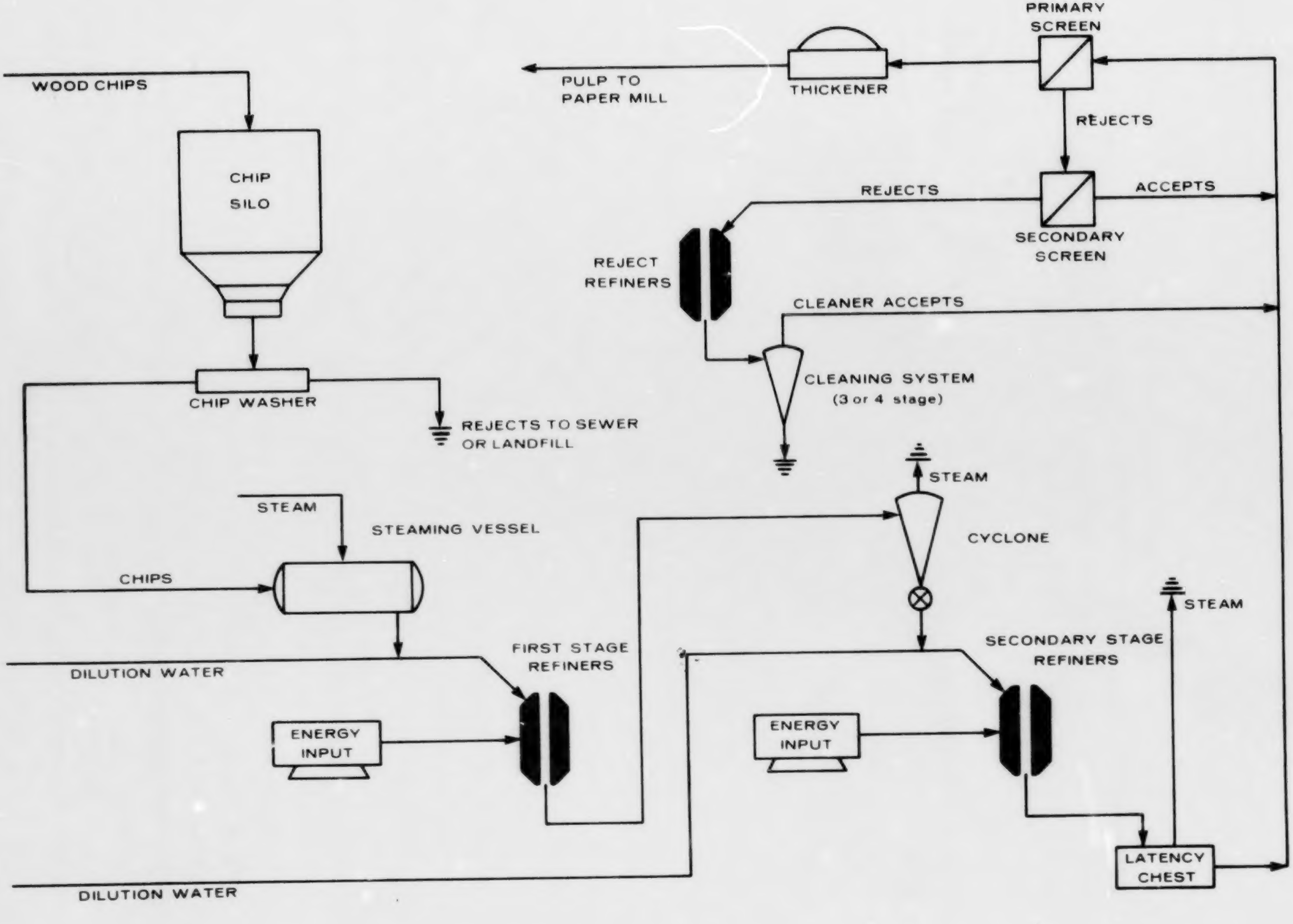
WOOD CHIPS
CHIP SILO
CHIP WASHER
REJECTS TO SEWER OR LANDFILL
STEAM
STEAMING VESSEL
CHIPS
DILUTION WATER
FIRST STAGE REFINERS
ENERGY INPUT
DILUTION WATER
PULP TO PAPER MILL
THICKENER
PRIMARY SCREEN
REJECTS
ACCEPTS
SECONDARY SCREEN
REJECTS
REJECT REFINERS
CLEANER ACCEPTS
CLEANING SYSTEM (3 or 4 stage)
STEAM
CYCLONE
STEAM
SECONDARY STAGE REFINERS
ENERGY INPUT
LATENCY CHEST

FIGURE 10 TYPICAL TMP PROCESS FLOWSHEET

the refiners. Most TMP and refiner groundwood mills have therefore installed chip washers upstream of the refiners. These wash the chips with water and remove the foreign material by difference in specific gravity and size. Most of the water used in the chip washers is recycled, but some effluent normally is discharged.

5.1.4 **Chemi-thermomechanical Pulp.** Some TMP mills add small amounts of sodium sulphite to the steaming vessel to further soften the chips. This improves the quality of the final pulp produced, but also lowers the yield and increases the discharge of organic material with the effluent.

This practice would technically classify the mill as a very high yield sulphite mill, but processes with "digesters" of a few minutes retention, at pressures under, say 500 kPa, have normally been considered chemi-thermomechanical (CTMP).

A few companies currently produce newsprint from TMP alone, without the addition of chemical pulp. Other mills produce newsprint and similar grades with TMP and very small additions of chemical pulp. The capability of any one mill to produce newsprint from 100% TMP depends on the paper machines, customer requirements, wood quality, and the level of operating skills available.

With pressure on many small newsprint mills to eliminate or treat the sulphite pulping effluent, conversion to TMP can be considered a realistic alternative. This normally involves the construction of a new TMP mill utilizing the former groundwood mill's woodroom, paper machines and utilities, and costs tens of millions of dollars. In addition to reducing effluent BOD, conversion to TMP reduces labour, wood, and chemical costs. Product quality may also be improved.

5.1.5 **Effluents.** Figures 8 and 10 indicate the reject stream from the tertiary cleaners and the rejects from the chip washer are the only sources of unusable fibre, and hence the sources of suspended solids in effluent from the system.

The cleaner reject stream, which may reach 1% of pulp production, can be minimised by good cleaner system design and operation. In mills with high losses from this source, much of the material is fibre which is discharged from the cleaner reject with the dirt. Each additional stage of centrifugal cleaning will generally cut the loss from this source by about 60%, obviously within the constraint that essentially all sand, dirt and chop (small wood fragments) must be removed from the product. The ultimate limitation on cleaner system efficiency is cost, since the additional stages necessary to achieve effective cleaning with low losses tend to require frequent operator attention and maintenance.

The chip washer rejects typically amount to about 5 kg/t pulp produced. This stream has been reduced to a relatively small solid waste disposal problem in those washers with the most effective recycle systems, although cost considerations are similar to those that apply to the cleaner rejects described above.

The cleaner rejects and the chip washer rejects can be relatively easily dewatered and landfilled, either directly or via an external primary effluent treatment system. This is now common practice.

Some fibre is continuously lost from mechanical pulp mills along with excess white water. This flow depends on the overall mill white water system design and can vary from 20 to 70 m^3/t pulp. The consistency of this stream depends primarily on the design of the saveall/pulp thickener. If the latter is an adequately sized modern design with no overflow of rich white water, the fibre in the lean white water discharged will be under 150 mg/L and may be as low as 60 mg/L in some cases. This is equivalent to 1.2 to 10 kg/t pulp, and is quite significant relative to the current suspended solids discharge regulations.

The concentration of suspended solids in the white water which must be discharged to sewer can often be reduced by modifying the pulp thickener. The flow of white water discharged can often be reduced by improving the overall white water system in the mill. Essentially, all fresh water entering the manufacturing process between the ingress of chips (or clean debarked logs) and the entry of the paper sheet to the dryer must leave the process at some point, primarily at the overflow of the thickener seal tank. Reduction of this water input is limited by various equipment details, as discussed in other sections of this manual, and also by the need to restrict the dissolved solids concentration in the system. The latter depends primarily on the pulping yield and the quantity of white water discharged, and is roughly inversely proportional to either. The maximum acceptable concentration is not well defined; further research in this field is probably necessary.

Suspended solids are also accidentally discharged from mechanical pulp mills as a result of equipment failure or human error. Such losses vary widely from mill to mill, and values from 7 to 50 kg/t production are common. The control of accidental losses is discussed in Section 14 of this manual.

In all mechanical pulping operations, some soluble organic materials are released from the wood, principally extractives and wood sugars, a small proportion of which are volatiles. The volatile components released in the mechanical pulping operations along with steam have been the subject of various studies which have shown this material to have a negligible effect on the environment. No regulations concerning such discharges have been formulated.

The water-soluble components, however, do have an environmental significance. Table 4 clearly demonstrates that the BOD discharge levels increase as the yield decreases. Toxicity levels are less documented; however, toxicity generally decreases with increasing yield.

Effluent flows depend on process design and the extent to which the mechanical pulp mill white water system is integrated with other pulp mills on-site. Typical values range from 25 to 100 m^3/t pulp, including the excess white water.

Regardless of any of the above-mentioned measures for the reduction of suspended solids discharges, essentially all the dissolved organic material separated from the wood will be discharged to sewer. There are currently no practical, proven ways of reducing this, although some research has indicated that in mills with low specific water consumption, the BOD discharges are lower than would be indicated by a simple material balance. All the effluents from a mechanical pulp mill can be treated in conventional external treatment facilities described in Section 13 of this manual. The criteria for selection of external versus the above internal measures are discussed in Section 14.

5.1.6 Atmospheric Emissions and Solid Waste Discharges. The only source of particulate emissions from mechanical pulping operations are the vents from the TMP refiners which contain mostly steam with a small quantity of fibre. Any atmospheric pollution problems due to particulate emissions are usually restricted to the immediate surroundings. Presuming that the trend toward the installation of TMP heat recovery systems continues, this source will disappear.

Solid wastes produced include screen, washer and cleaner rejects. Up to about 5 kg bull screen rejects per tonne pulp may be rejected to landfill, but are more commonly refined and recovered. Up to 5 kg/t chip washer rejects (mostly sand and grit) and/or 5 to 20 kg/t cleaner rejects may be landfilled if they are not discharged to the sewer system.

5.2 Chemical Pulping (General)

In chemical pulping, fibre separation is accomplished principally by the expenditure of chemical energy. Pulp yield is normally in the range of 35 to 57%. For the majority of chemical pulp grades, about 95% of the lignin is removed in pulping.

The two major chemical pulping processes are sulphite, which operates in a low pH or acid environment, and kraft, which is alkaline. Their general relationship, in terms of pH range and chemical pulping species, is shown in Figure 11. It is apparent that

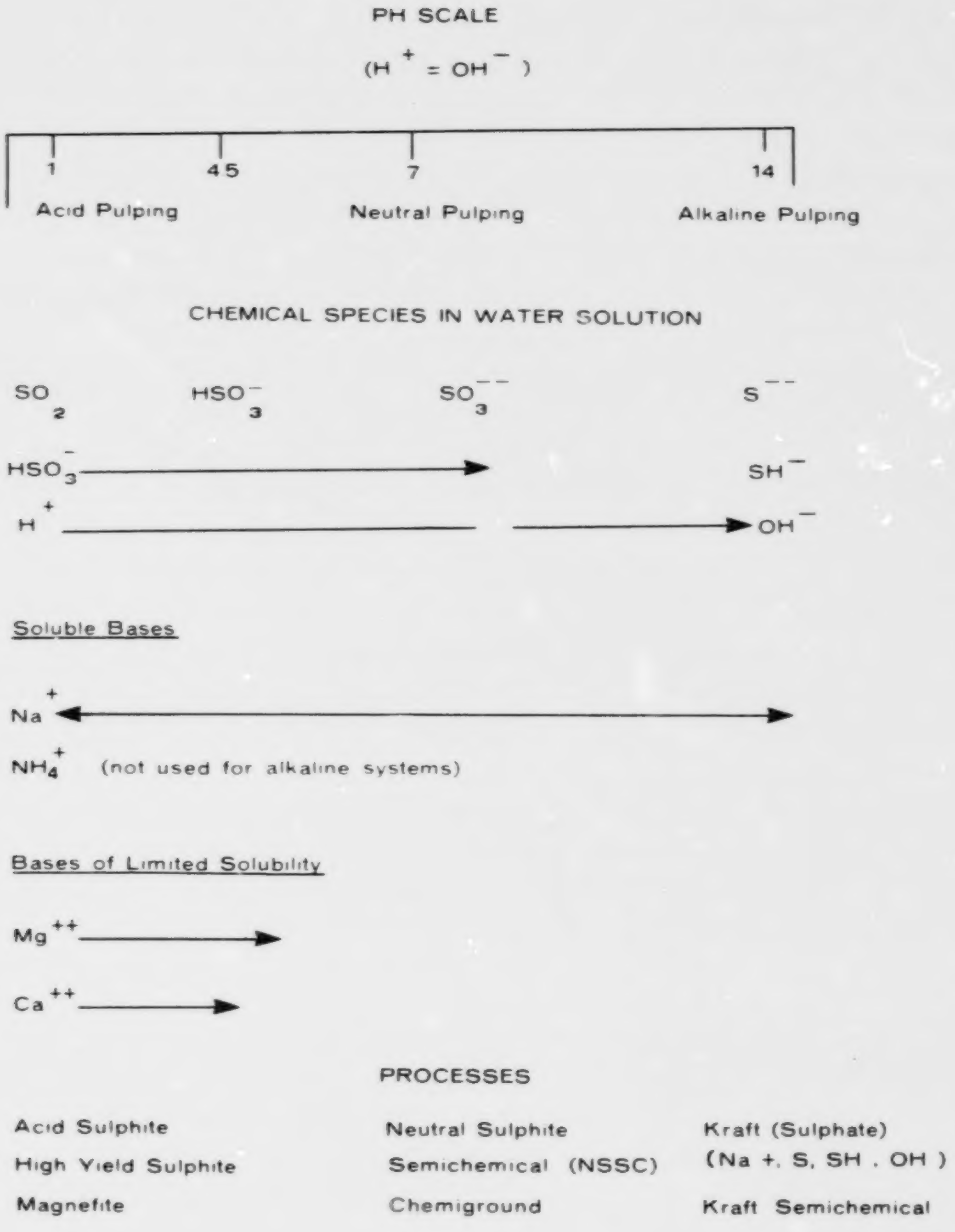
PH SCALE
($H^+ = OH^-$)
1
4.5
7
14
Acid Pulping
Neutral Pulping
Alkaline Pulping
CHEMICAL SPECIES IN WATER SOLUTION
SO_2
HSO_3^-
SO_3^{--}
S^{--}
HSO_3^-
SH^-
H^+
OH^-
Soluble Bases
Na^+
NH_4^+ (not used for alkaline systems)
Bases of Limited Solubility
Mg^{++}
Ca^{++}
PROCESSES
Acid Sulphite
High Yield Sulphite
Magnefite
Neutral Sulphite
Semichemical (NSSC)
Chemiground
Kraft (Sulphate)
(Na^+, S, SH, OH)
Kraft Semichemical

FIGURE 11 CHEMICAL CONDITIONS FOR THE PRINCIPAL CHEMICAL PULPING PROCESSES

the pH and chemical composition of the various possible cooking liquors cover broad ranges and should be seen as a continuum. The basic chemical ions of sulphur, oxygen, and an alkali exist in different chemical states depending on the process employed. Sulphur compounds are utilised over the entire range of pH.

Acidic and alkaline hydrolysis effects are reduced if the pulping system is maintained close to neutral pH, an effect which is used in the higher yield processes. Under low and high pH conditions, hydrolysis becomes very pronounced because much of the shorter-chained hemicellulose dissolves in the cooking liquor. Woods containing high percentages of resins and fats are readily pulped and solublized in alkaline media due to saponification-type reactions. Sulphite systems, on the other hand, work best with woods having low resin or pitch content.

The main operating variables in pulping are:

- liquor composition,
- cooking time,
- pH,
- digester operating pressure, and
- digester operating temperature.

Since the digester operates at saturation pressure, except in the acid sulphite process, the cooking temperature is normally defined by the pressure.

Because the sulphite process produces brighter and more easily bleached pulp, it remained the main method of chemical pulp production until about 1946, when bleaching the darker kraft pulp without serious loss of strength was achieved. Today, most of the chemical pulp produced is from the kraft process. The two main factors that made the sulphite process less competitive were its sensitivity to the wood species and the difficulty of recovering the cooking chemicals and utilizing its waste products, which correspond to half the wood substance. The kraft and sulphite processes will be discussed separately, followed by consideration of hybrid sulphite/mechanical process.

5.3 Kraft Pulping

The kraft process, also known as the sulphate process, is now the dominant chemical pulping process. Chemical recovery and bleaching technology developed in the 1930s and 1940s, as well as continuous research and development, has promoted its growth since 1950. Its versatility and flexibility make it suitable for use with most wood species. Extractives of certain wood species which lead to problems with pitch in acid sulphite pulping are dissolved or dispersed by alkaline liquor. The carbohydrates which tend to degrade in an acidic medium are largely alkali-stable in the kraft process. The relative rapidity of the cooking process and the high strength properties of its pulp are further advantages. The principal drawbacks relate to the dark colour of the unbleached pulp and its bleaching costs. A relatively large amount of residual condensed lignin remains in the pulp and cannot be removed by further cooking without extensive degradation of the carbohydrate fraction. This residual lignin is responsible for the dark colour of unbleached kraft pulp, and is much harder to remove by bleaching than the lignin in sulphite pulps. Multistage bleaching is used to overcome this drawback, as described Section 7 of this manual.

5.3.1 **Process Description.** Kraft pulping utilizes an alkaline solution referred to as white liquor, typically about 10% concentration of Na_2S and NaOH, to delignify the wood for fibre separation. The series of cycles characteristic of this process is schematically illustrated in Figure 12. The spent cooking liquors, known as black liquor, are separated from the pulp following digestion and treated in the chemical recovery system. The recovery system regenerates the cooking chemicals of Na_2S and NaOH while utilizing the heat value of the organic residue to generate steam for the process. The chemical recovery system is described in a separate section of this report. Typical analyses of kraft black liquor are shown in Table 5. Actual values vary due to differing wood species, pulping techniques, and analytical procedures.

The cooking process can be either batch or continuous. In continuous cooking, the system being installed in the majority of new mills today, the chips are usually preheated in a steaming vessel before entering the digester. Pre-steaming removes air, noncondensible gases, and volatile constituents such as the terpenes. After entering the continuous digester, the chips are impregnated with cooking liquor at a controlled temperature to ensure uniform penetration of the liquor. After adequate impregnation, the temperature is raised to the cooking temperature of around 165°C by indirect heating of circulated cooking liquor and held there for about one hour. The pulp is then quenched to about 125°C with wash liquor.

In most cases, diffusion washing is then carried out in the lower region of the digester, removing a considerable proportion of the spent chemicals. The wash temperature in the lower zone of the digester is 80 to 85°C. This ensures suitable blow conditions with little or no mechanical damage to the fibres. A continuous Kamyr digester schematic is shown in Figure 13.

In batch cooking, the chips and cooking liquor are charged into the digester which is then sealed and raised to operating pressure and temperature according to a pre-

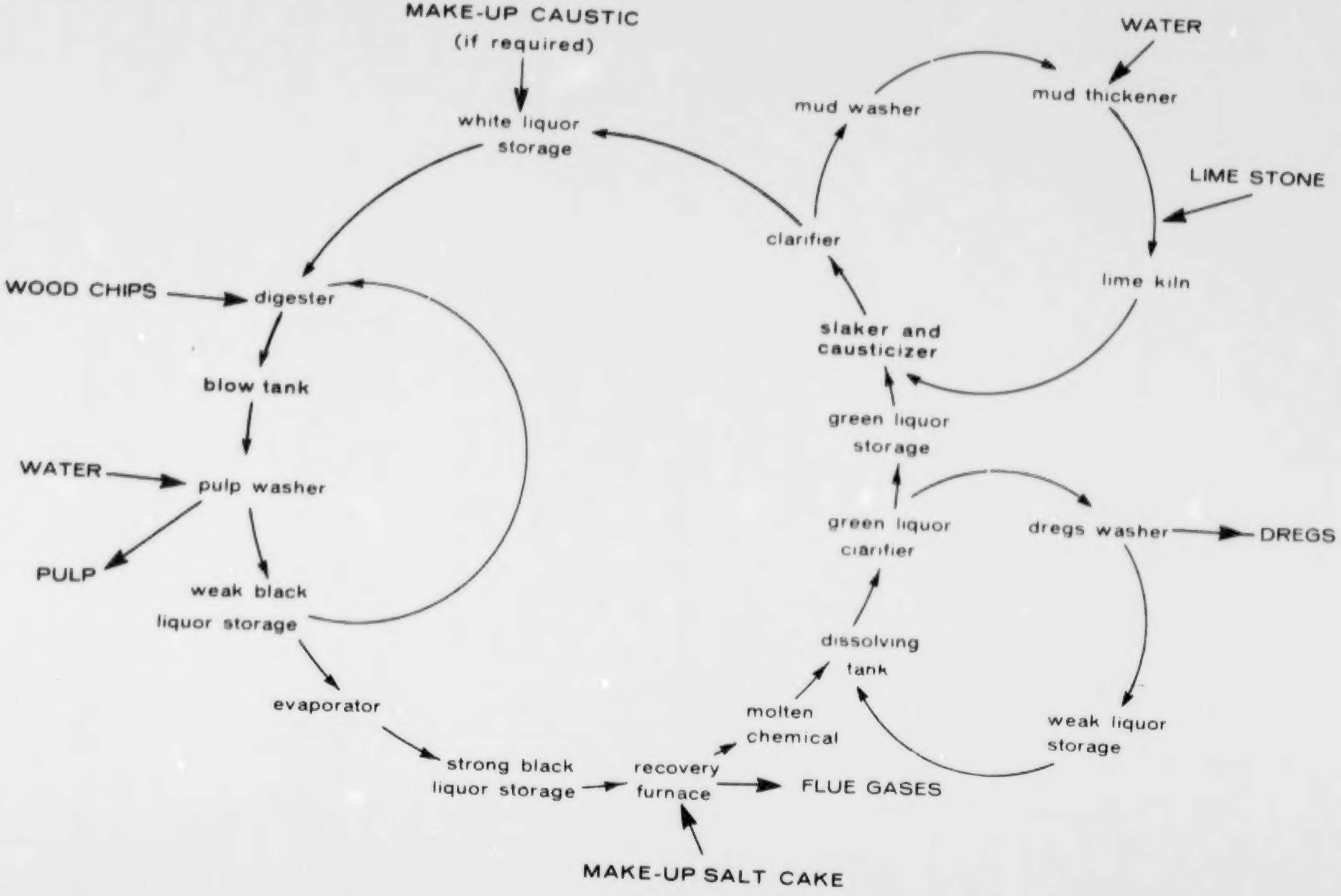
MAKE-UP CAUSTIC
(if required)
white liquor storage
WATER
mud washer
mud thickener
LIME STONE
clarifier
lime kiln
WOOD CHIPS
digester
slaker and causticizer
blow tank
green liquor storage
WATER
pulp washer
green liquor clarifier
dregs washer
DREGS
PULP
weak black liquor storage
dissolving tank
evaporator
molten chemical
weak liquor storage
strong black liquor storage
recovery furnace
FLUE GASES
MAKE-UP SALT CAKE

FIGURE 12 PRINCIPAL RECYCLES IN KRAFT PULPING AND CHEMICAL RECOVERY

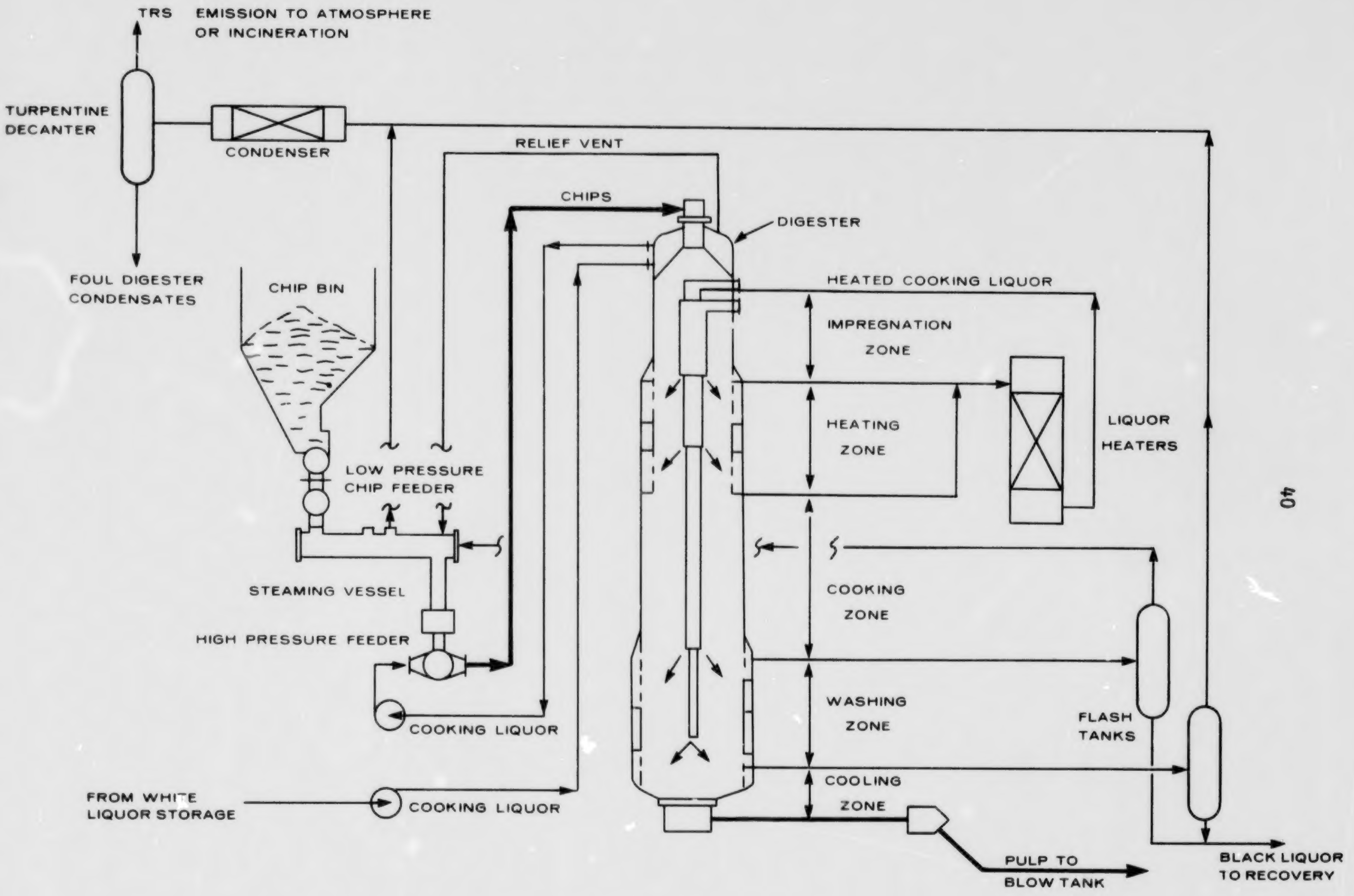
TRS
EMISSION TO ATMOSPHERE OR INCINERATION
TURPENTINE DECANTER
CONDENSER
FOUL DIGESTER CONDENSATES
RELIEF VENT
CHIPS
DIGESTER
CHIP BIN
HEATED COOKING LIQUOR
IMPREGNATION ZONE
HEATING ZONE
LIQUOR HEATERS
LOW PRESSURE CHIP FEEDER
STEAMING VESSEL
COOKING ZONE
HIGH PRESSURE FEEDER
WASHING ZONE
FLASH TANKS
COOKING LIQUOR
COOLING ZONE
FROM WHITE LIQUOR STORAGE
COOKING LIQUOR
PULP TO BLOW TANK
BLACK LIQUOR TO RECOVERY

FIGURE 13 TYPICAL CONTINUOUS KAMYR DIGESTER

TABLE 5 TYPICAL BLACK LIQUOR ANALYSIS

	Percentage of dry solids		
	Pine (Mill 1)	Pine (Mill 2)	Spruce
Lignin	28.9	31.1	41
Hemicellulose and sugar	1.1	1.3	-
Extractives	6.7	5.7	4
Saccharinic acids		18.8	28
Acetic acid	3.5	5.2	5
Formic acid	4.5	3.1	3
Other organic acids	5.5		-
Methanol			1
Unknown organic compounds	19.0	5.8	
Inorganic salts	18.6	20.3	
Organically combined Na	10.1	8.7	
Unknown inorganic compounds	2.1		
Sulphur, S			3
Sodium, Na			16

Note: The above data are summarised from EUCEPA (European Committee for Cellulose and Paper) Symposium on Recovery of Pulping Chemicals, Helsinki (1968).

determined schedule. The most common way of heating it is by direct addition of steam, but some or all of the heating may be performed by extracting liquor, heating it indirectly in an exchanger with steam, and recycling the hot liquor to the digester. After digestion, the pulp is blown hot into a blow tank where it is diluted with black liquor and then pumped to the washing department. Figure 14 illustrates a typical batch cooking system.

Terpenes and other volatile constituents distil off during the initial stages of the cook and must be relieved. The maximum cooking pressure, typically about 600 kPa, is reached in 1 to 3 hours; the complete operating cycle from charging until the digester is blown and ready for the next charge is about 4 hours.

Terms such as active alkali, effective alkali, sulphidity, etc., are commonly used in the kraft industry to describe the chemical composition of the liquors. It is also common practice to express the quantities of the various sodium compounds in terms of

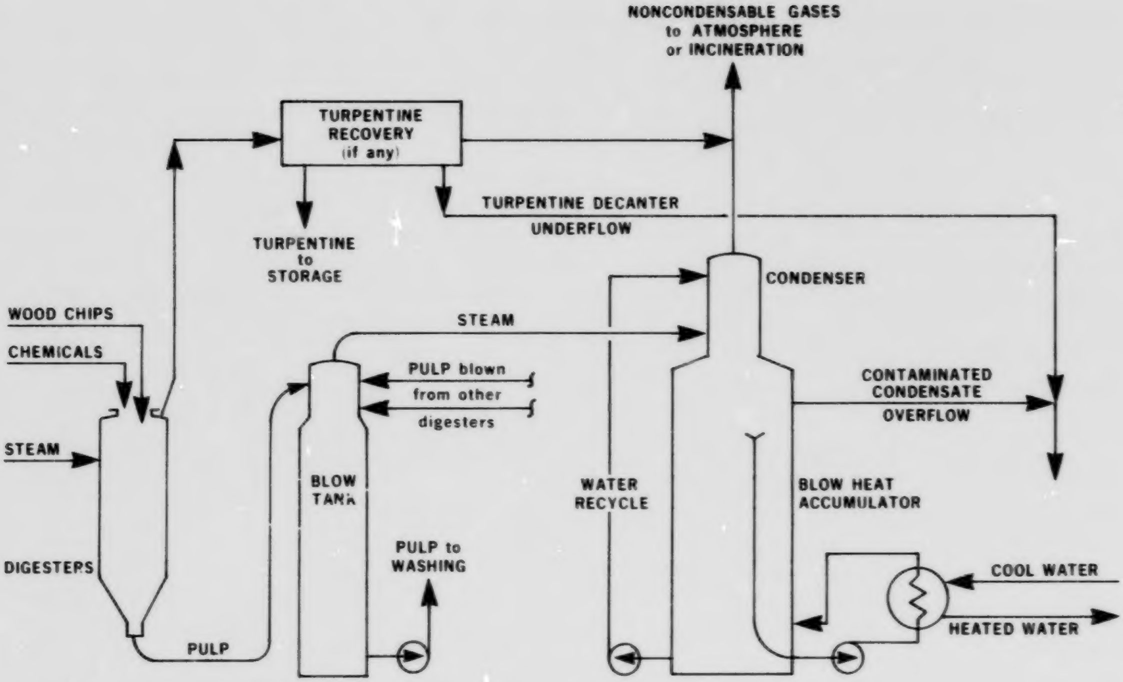
NONCONDENSABLE GASES
to ATMOSPHERE
or INCINERATION
TURPENTINE
RECOVERY
(if any)
TURPENTINE DECANTER
UNDERFLOW
TURPENTINE
to
STORAGE
CONDENSER
WOOD CHIPS
CHEMICALS
STEAM
STEAM
PULP blown
from other
digesters
CONTAMINATED
CONDENSATE
OVERFLOW
BLOW
TANK
WATER
RECYCLE
BLOW HEAT
ACCUMULATOR
PULP to
WASHING
DIGESTERS
COOL WATER
HEATED WATER
PULP

FIGURE 14 TYPICAL BATCH DIGESTER SYSTEM

their equivalent weight as sodium oxide (Na_2O). The compound Na_2O does not actually exist in the pulping liquor and is employed for convenience only. Table 6 lists these terms and their definitions.

5.3.2 Brown Stock Washing. The pulp from the blow tank is intimately mixed with the black liquor and must be separated from it. This process is known as brown stock washing, since the prime objective of this operation was at one time to remove the black liquor from the pulp. However, with the energy costs and environmental constraints of the 1980's, it is essential to view the process objective as separation of the pulp fibres from black liquor solids with the addition of as little water as possible.

The quality of separation is conventionally defined in terms of the soda loss, which is the concentration of sodium sulphate which remains with the pulp leaving the last washing stage and is normally expressed as kg Na_2SO_4/ODt. The quantity of organic material is not normally measured but is approximately proportional to the soda loss. (The soda loss is most often expressed in terms of Na_2SO_4, but may also be expressed as kg Na_2O/ODt, particularly by those anxious to make washer loss appear low. It is essential to be aware of the units used in evaluating washer loss data.)

TABLE 6 STANDARD DEFINITIONS IN KRAFT PULPING CHEMISTRY (all Chemicals as Na_2O)

Term	Definition
Total Chemical	All Na salts as Na_2O (excluding NaC l)
Active Alkali	$NaOH + Na_2S$
Effective Alkali	$NaOH + 1/2\ Na_2S$
Sulphidity	$\frac{Na_2S}{NaOH + Na_2S} \times 100$
Total Alkali	$NaOH + Na_2S + Na_2CO_3 + Na_2SO_4$
Total Titratable Alkali	$NaOH + Na_2CO_3 + Na_2S$
Causticity	$\frac{NaOH}{NaOH + Na_2CO_3} \times 100$
Activity	$\frac{NaOH + Na_2S}{NaOH + Na_2S + Na_2CO_3} \times 100$

Virtually all the organic material that leaves the washers with the pulp will be discharged to the effluent system in some form. Most of it is washed out of the pulp in the subsequent screen room, and represents up to 30 kg BOD/t pulp in extreme cases. This particular organic material contains significant quantities of resin acids and other large molecules which are toxic to fish and resistant to biological treatment; its impact on final effluent quality and treatment costs is therefore usually greater than would be indicated by consideration of its BOD alone.

Residual black liquor solids that are not removed from the pulp in the screen room will react with the chlorine in the subsequent bleach plant and be discharged to the effluent as chlorinated lignins. In the case of mills that produce unbleached grades of kraft, this residual black liquor is mostly washed out of the pulp in the paper machine or pulp dryer and appears in the mill effluent in the excess white water.

The quantity of water added to the system to achieve the separation is expressed by the dilution factor, which is the ratio of shower water mass flow that does not exit with the pulp sheet to the pulp mass flow. It is dimensionless and is useful for comparing and predicting washer performance. Typical values in mill operations are 2 to 4:1. The amount of dilution water used in washing must be controlled carefully as it not only influences washing efficiencies but also must be evaporated in the recovery plant.

The dilution factor and the number of stages of washing installed are the fundamental variables which control washing efficiency. The physical design, construction, and operation of the equipment used is also important and is discussed below.

The concentration of dissolved solids of the black liquor produced is a key variable in the definition of the performance of a brown stock washing system, and is normally known as consistency in the pulp industry.

In any given system, the soda loss will always be reduced if the dilution factor is increased. However, this increases the volume and lowers the consistency of the black liquor which then has to be evaporated, requiring investment in evaporator and recovery furnace capacity as well as incurring energy costs.

Washing efficiency can also be increased by installing additional washing stages, or better equipment, again incurring additional capital and maintenance costs. However, there is generally no substantial increase in energy consumption; in many cases, a net reduction in energy consumption is achieved by the installation of an additional washing stage.

Any increase in washing efficiency transfers organic material and chemicals from the sewers to the recovery furnace; the quantity of steam generated is thereby increased, provided that the recovery furnace is adequately sized for the mill's production.

When considering data on soda losses from the more efficient brownstock washing systems, it is necessary to distinguish between bound and unbound soda. Some of the sodium salts, typically about 3 kg/t pulp, are intimately bound within the fibres due to sorption and cannot be separated from the pulp by simple washing with water. The remainder of the sodium salts are considered to be unbound soda and can be separated from the pulp if sufficient washing equipment is installed.

Attaining the optimum balance between washing efficiency, energy costs, and capital costs requires a complex blend of process and mechanical engineering, as well as economics; the best results can be obtained only in new mill installations. However, most older installations can be upgraded to approach the performance of new systems by the installation of additional stage(s) of washing equipment or the installation of more modern equipment. The washing systems in most older mills are far from the economic optimum, due to a lack of appreciation of the overall economics at the time the systems were designed and to the changes in equipment design and energy costs that have taken place. This tends to cause relatively high discharges of residual black liquor from many older mills. The practical limit on washing efficiency corresponds to a soda loss of about 5 kg/t pulp of unbound soda, with another 3 kg/t lost as bound soda, and many modern mills are designed to this criterion.

The BOD of the organics lost with the soda is proportional to the soda loss. Figure 15 shows curves for washer loss versus dilution factor calculated for typical three and four stage washing systems for a specific mill. The actual values will vary with local conditions, but the shape of the curves is typical. Note the effect of screen room closure; and refer also to Section 6.5 of this manual.

The calculations used to predict the efficiency of washing efficiency are complex; although simplified methods have been presented in the literature, it is best to use a computer to allow effective examination of the many operating and design alternatives available, and to determine the best design and operating strategy.

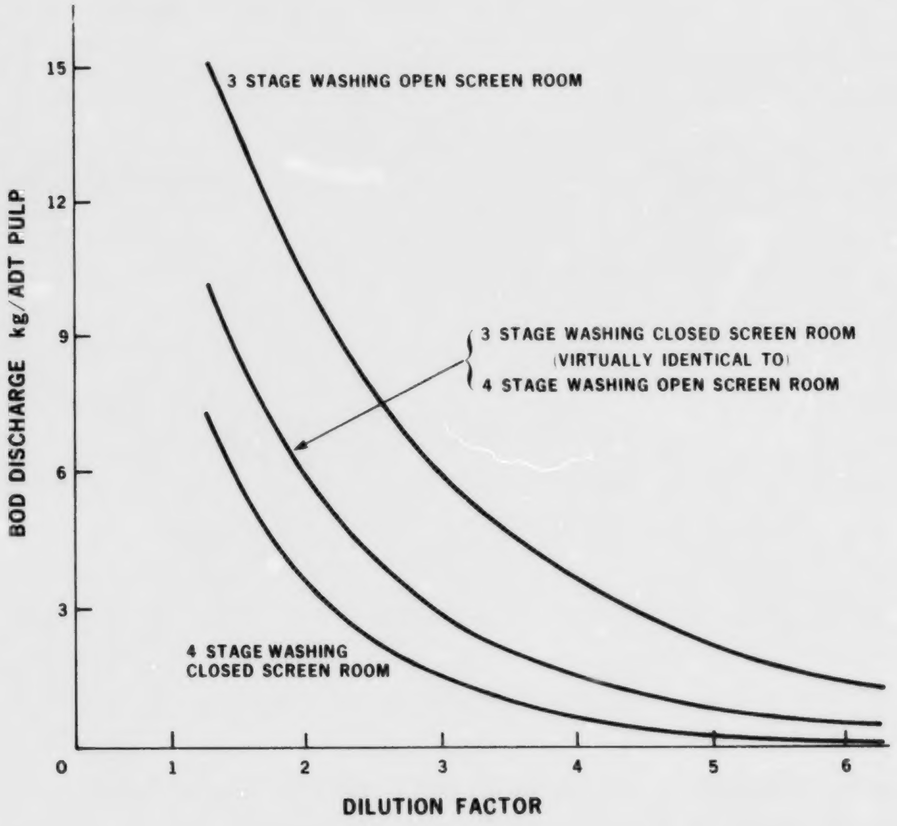

FIGURE 15 BOD LOSSES VS DILUTION FACTOR FOR KRAFT PULP WASHING SYSTEM

The foregoing discussion of the process concepts of brown stock washing is applicable to all of the alternative equipment discussed in the remainder of this section. Brown stock washing has traditionally been carried out on a series of counter-current vacuum drum filters designed to displace the black liquor at as high a concentration as possible. The clean wash water is introduced at the last stage and the pulp at the first one. Each stage washes the pulp from the previous stage, using the wash liquor discharged from the subsequent stage. A typical three-stage system flowsheet is illustrated in Figure 16; a typical vacuum drum filter is shown in Figure 24.

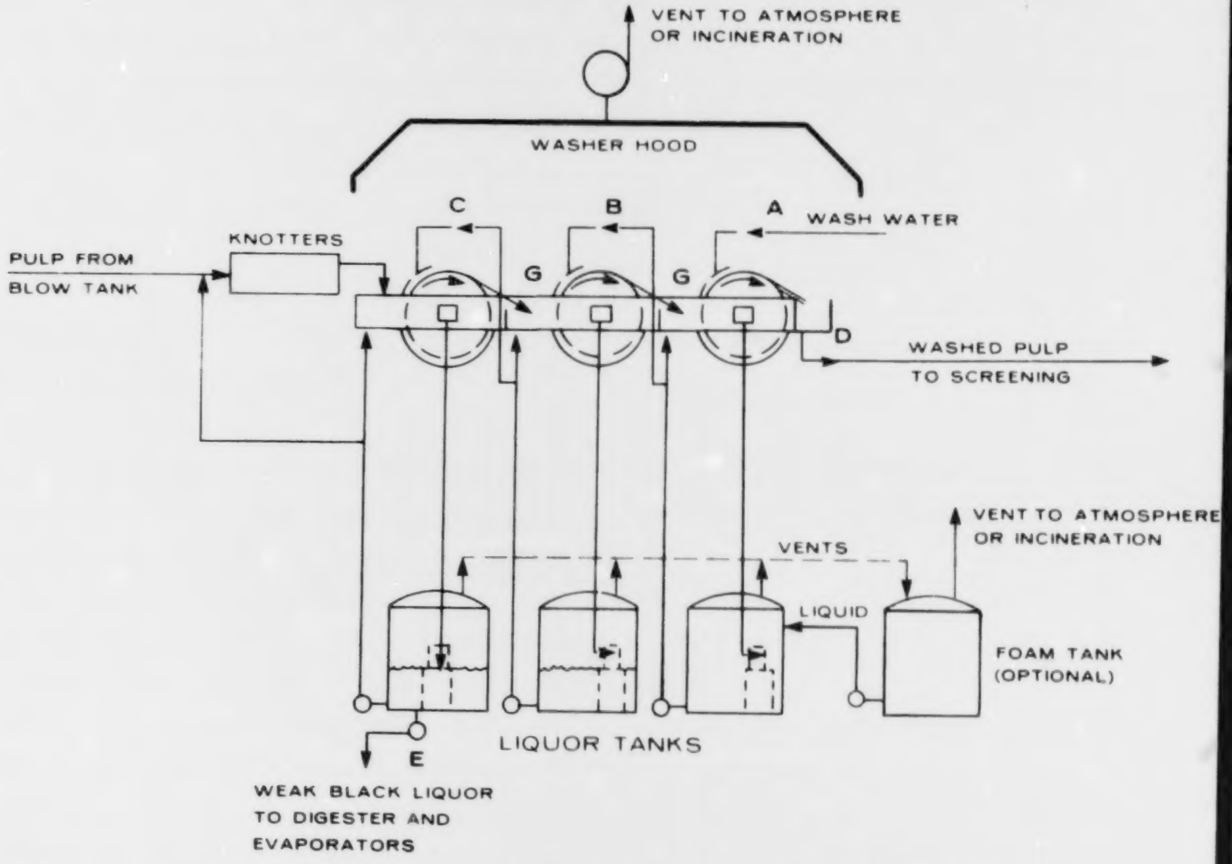
VENT TO ATMOSPHERE
OR INCINERATION
WASHER HOOD
C
B
A
WASH WATER
KNOTTERS
PULP FROM
BLOW TANK
G
G
D
WASHED PULP
TO SCREENING
VENT TO ATMOSPHERE
OR INCINERATION
VENTS
LIQUID
FOAM TANK
(OPTIONAL)
LIQUOR TANKS
E
WEAK BLACK LIQUOR
TO DIGESTER AND
EVAPORATORS

FIGURE 16 TYPICAL BROWN STOCK WASHING FLOWSHEET (Drum Type)

The pulp is separated from the spent liquor by the vacuum filter, which consists of a wire cloth covered cylinder that rotates in a vat containing the pulp slurry. The lower section of the drum is submerged in the pulp. Vacuum created by the filtrate liquor flowing down a drop leg is applied by means of internal valving as the relevant sector of the drum enters the slurry. The black liquor drains through the wire cloth leaving the pulp on the face of the wire. The pulp mat builds up as the drum rotates through the slurry and is retained on the face of the wire by the vacuum applied inside the cylinder.

After emerging from the slurry, the pulp mat is washed with water "A" or filtrates "B" or "C", applied through multiple showers located over the pulp sheet (Figure 16). Residual black liquor in the mat is displaced out of the sheet. Finally, the sheet continues to rotate on the drum to a point where the vacuum is cut off and the washed pulp is removed from the wire face at about 12 to 15% consistency. It then enters the mixing phase "G" between the stages. Here, repulpers break up the thickened sheet and dilute it with weaker liquor from the subsequent stage. The fibres are thus agitated to transfer further retained dissolved solids to the liquor prior to extraction on the next vacuum filter.

Foam control is a major problem in vacuum washing, particularly in the case of pine liquors that are high in resin and fatty acid content. Foam fills the voids between fibres and prevents free draining of the liquor. It reduces the washing efficiency of showers by lowering diffusion rates and permitting channelling to occur. Large volumes of foam can form in tanks and overflow to sewers, causing chemical losses and contributing substantially to effluent BOD and toxicity.

Washing of the pulp on drum filters is accomplished as the result of two operations: dilution and agitation of the stock in the vat with weaker liquor, and subsequent thickening on the drum; and displacement of the vat liquor with shower liquor on the filter drum.

The displacement ratio (DR) is defined as the ratio of soluble material removed in the shower zone of the filter compared to the maximum soluble material than could be removed if displacement were perfect. It is the major tool used in defining the washing efficiency for any single washing stage and is a measure of all the operating variables. Washer efficiency will, of course, vary with the dilution water added; however, it is reasonable to assume that the displacement ratio will be unaffected by small changes in the dilution factor, allowing prediction of the effect of alternative operating conditions.

In the first stage of the system, the displacement ratio is relatively high because the pulp and its liquor are relatively free of air. It will normally range from 0.8 to 0.9, depending on the dilution factor. The DR for intermediate stages is normally between 0.5 and 0.7. The displacement ratio values for each stage are combined to provide an overall washing efficiency for the system. Operating conditions such as washer speed, specific loading, sheet thickness, pulp consistency, viscosity of liquor, rate of shower water, rate of stock flow, vacuum, and temperature, etc., will affect the displacement ratio actually achieved, and hence the washing efficiency.

The traditional countercurrent drum washing operation offers the advantages of efficient washing with low dilution of liquor and low heat losses, and well proven technology with a number of competitive equipment suppliers. However, the large circulating liquor volumes (about 100 m^3/t per stage) require high pumping energy and are potential sources of major accidental losses to sewers in the event of equipment failure. Washers of this type can remove 98 to 99% of the spent chemicals and dissolved solids, attaining the practical limit of soda loss mentioned above. This normally requires five stages of washing, but few mills have installed more than four stages, and three is common. Mills that practice diffusion washing in the digester can attain high washing efficiencies with fewer drum stages.

The drum washing equipment described above is used in the majority of mills, with relatively minor variations in equipment and system design. Other equipment introduced in the past 10 years for pulp washing offer some advantages, although usually at an increased capital cost. The principal recent development in brown stock washing is the continuous diffusion washer introduced by Kamyr in the 1960s. There are now about 15 such installations in Canada and about 200 world-wide.

Figure 17 shows a two-stage brown stock diffusion washer. It consists of a set of concentric rings of double screen plates mounted on a set of arms, normally three or six. The entire screen assembly is moved upwards at the same rate as the stock by a set of externally mounted hydraulic cylinders, and then downstroked in about 1 second after completing the upstroke. This keeps the screens from plugging by cleaning them once every 1 to 2 minutes. Pulp flows upwards at about 10 m/h through the annular spaces between the rings. Wash water is introduced into the pulp midway between the rings through a set of rotating nozzles suspended from the scraper, which rotates at about 8 rpm. The wash water flows across to the screens, displacing the liquor which enters with the pulp. A dilution factor of 2 to 3 is normally applied. Filtrate drawn through the perforated screen plates flows down through the hollow support arms and is extracted through a pack box and external piping out of the tower. In the illustration shown, the filtrate flows through the arms to a central pipe and then out. The driving force pushing stock up through the tower is either a pump or, if the diffuser is connected to a continuous digester, the pressure in the digester itself.

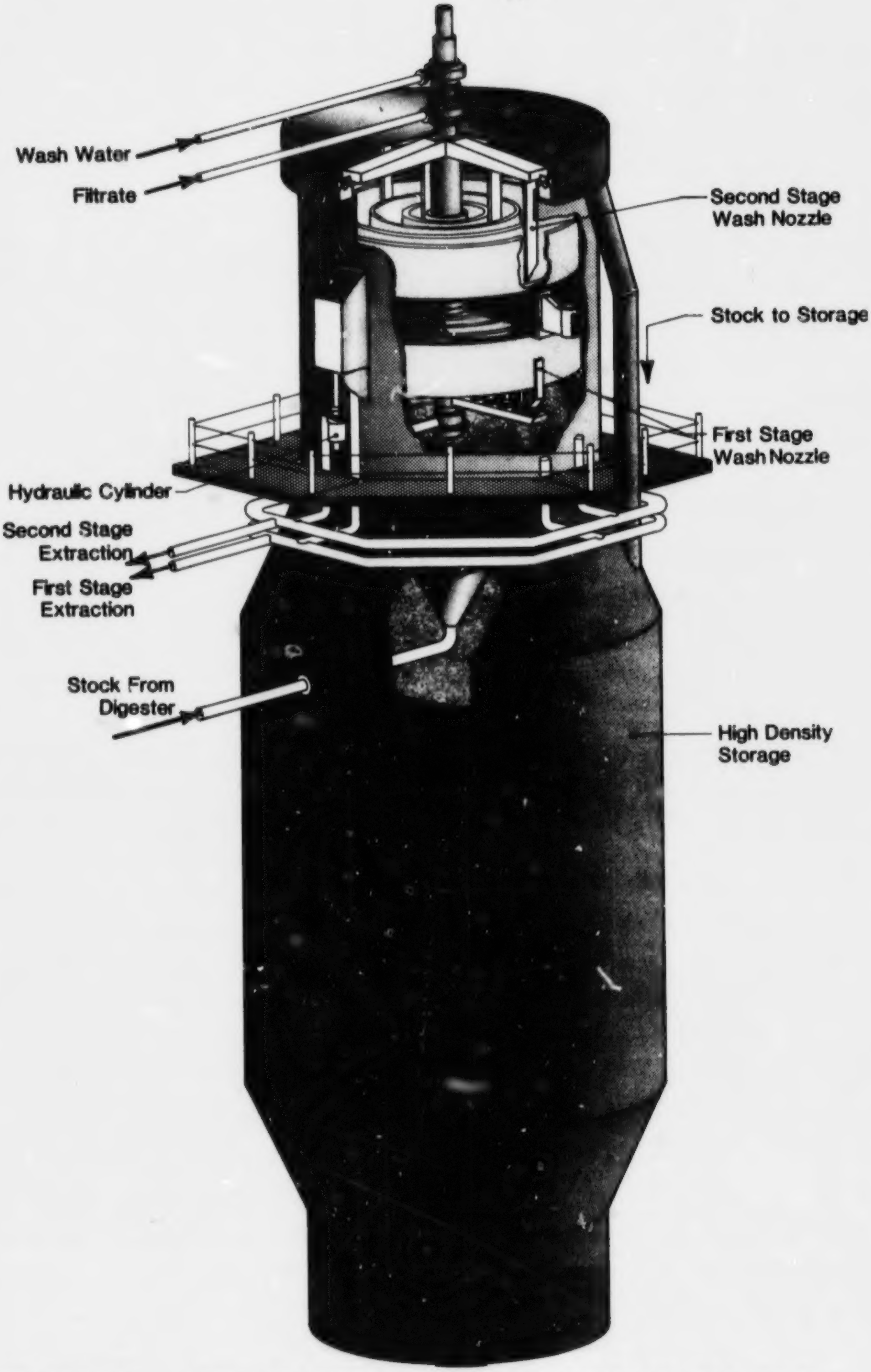
Wash Water
Filtrate
Second Stage Wash Nozzle
Stock to Storage
First Stage Wash Nozzle
Hydraulic Cylinder
Second Stage Extraction
First Stage Extraction
Stock From Digester
High Density Storage

FIGURE 17 TWO-STAGE BROWN STOCK DIFFUSION WASHER (Kamyr Inc.)

The stock and wash temperatures are normally about 50 to 70°C; the system is enclosed but not pressurised. Normally, the pulp consistency is 10 to 14%; it is kept approximately constant throughout the washing operation.

Two or more stages of diffusion washing can be installed in series; if desired, it is possible to perform part of the washing in a diffusion washer and the remainder in conventional drum washers. Diffusion washers have the advantage of avoiding the large recycling water flows characteristic of the conventional washers. This reduces the difficulty of avoiding spills and leaks due to human error or equipment failures. Intimate mixing of significant quantities of air into the pulp, which causes foaming with its attendant tendency to overflows to sewer as well as the emission of substantial flows of humid air contaminated with malodourous TRS gases, is also eliminated.

A more recent introduction is the continuous belt washer, which operates by showering a pulp mat on a continuous mesh belt while draining the liquor off below. Several stages of washing can be incorporated on one belt by segregating the liquor collection pans under the belt and operating the showers countercurrent to the pulp flow. Only a few of these washers have been built; further operating experience is required to fully evaluate them. However, they offer many of the same advantages as the diffusion washer described above.

Presses have been incorporated into some washing systems, usually at the last stage, to remove as much black liquor as possible from the pulp prior to entry to the screen room.

5.3.3 **Turpentine Production.** The vapours discharged from the digester (refer to Figures 13 and 14) contain up to about 6 kg turpentine per tonne of pulp, depending on the wood species and cooking conditions. These vapours are normally condensed, a prerequisite for an odour control system. Turpentine recovery reduces the BOD and toxicity of the effluent, since the liquid has a BOD in the order of 1 kg/kg turpentine.

Figure 18 illustrates the operation of a batch turpentine recovery system. Turpentine has a specific gravity of about 0.8, so it collects on the surface of the condensed water. The water level in the decanter is controlled by the height of the inverted "U" discharge line. The turpentine discharge line is located above this level so that reasonably pure turpentine is decanted off. The underflow, which contains terpenes, terpinols, methanol, etc., is foul smelling, toxic to fish, and has a BOD of up to about 4 kg/t pulp.

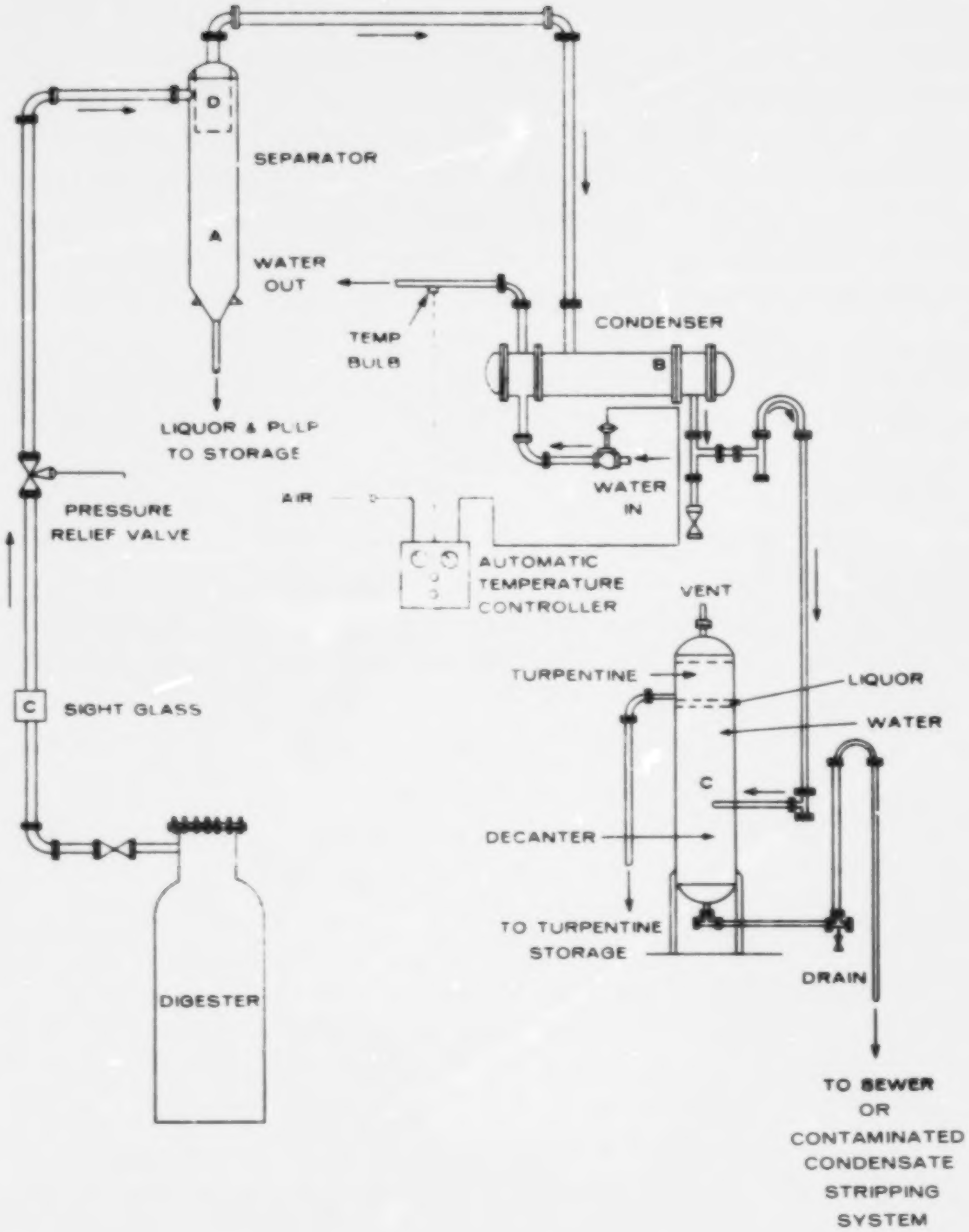
D
SEPARATOR
A
WATER
OUT
TEMP
BULB
CONDENSER
B
LIQUOR & PULP
TO STORAGE
WATER
IN
AIR
PRESSURE
RELIEF VALVE
AUTOMATIC
TEMPERATURE
CONTROLLER
VENT
TURPENTINE
LIQUOR
WATER
C
SIGHT GLASS
C
DECANTER
TO TURPENTINE
STORAGE
DRAIN
DIGESTER
TO SEWER
OR
CONTAMINATED
CONDENSATE
STRIPPING
SYSTEM

FIGURE 18 TYPICAL BATCH TURPENTINE RECOVERY UNIT

Several more complicated and more efficient turpentine recovery systems have been developed, all operating on the principle of separation of turpentine by density difference. In all cases, the recovery efficiency is substantially reduced if there is significant carry over of black liquor from the digester in the relief gases, which raises the BOD of the underflow substantially. The recovered turpentine is purchased by refining companies, or is used as fuel in the mill, most commonly in the lime kiln.

5.3.4 **Effluents.** In addition to the turpentine decanter underflow discussed above, the organic material lost from the pulp washers represents a major mill effluent. Typical BOD discharges are shown in Figure 15.

After washing, the pulp is normally routed to the screen room where it must be diluted to about 2% consistency so that the screens will function, and later be rethickened as described in Section 6. Most of the organic material remaining in the pulp after the washing stage is finally sewered, either directly in the screen room or in a subsequent bleach plant or paper mill where the stock is successively diluted and rethickened.

Because of the high flows of black liquor and pulp, there is a potential for high BOD and suspended solids losses to sewer due to human error and equipment malfunction. Suitable equipment and operator training are essential to minimise such losses. Many modern mills have installed spill collection systems to reduce such effluent discharges because they can frequently be large enough to cause serious operating difficulties in a waste treatment plant. Spills in the kraft pulping area are sometimes the highest single effluent source in a mill and normally contribute a significant proportion of the total effluent BOD, except in some new mills with integral spill control systems. Actual values vary widely from mill to mill and from day to day, and depend on the quality of engineering, operation and maintenance. Refer to Section 14 for further discussion on the prevention and control of accidental losses.

5.3.5 **Atmospheric Emissions.** Reduced sulphur gases are the best known atmospheric emissions from kraft mills due to their characteristic, unpleasant odour. The kraft pulping process generates about 2 kg of total reduced sulphur (TRS) per tonne pulp, and these gases will exit the system at some point. The normal emission points in the pulping and washing area are shown on Figures 13, 14 and 16.

The reported emission rates vary widely, partly due to real variations and partly due to the technical difficulties and expense associated with emission measurement. Batch digester operations tend to strip the TRS gases out of the pulp while blowing the digester, so that the principal emission is from the turpentine decanter vent or the blow heat recovery system vent if the latter is not operating effectively, whereas in continuous digesters the emission is more evenly split between the digester vent and the pulp washer vent. If continuous diffusion washers are used, the TRS emission is very small, but the gases concerned will be discharged at the evaporators. Refer to the overall mill TRS emission diagram in Figure 30.

Since the control of the digester TRS emissions is integrated with the control of emissions from other departments, it is discussed in Section 14.4. The only effective method of controlling pulp washer emissions is incineration. A number of mills have installed systems to use the vent gases as combustion air in a boiler. This necessitates a relatively tight hood around the washers to minimise the volume of air to be handled and usually requires a condenser to remove excessive amounts of water vapour. Since the boilers are not normally adjacent to the washers, the system can be costly although the technology is relatively simple and reliable. The capital cost would be several hundred thousand dollars.

5.3.6 Solid Waste. The knotters remove a few percent of the pulp flow immediately before the washers. These knots are normally broken down by refining and/or recooked for recycle to the process. However, failures in the knot recovery system are relatively frequent, and many mills find it necessary to dump knots to landfill or the sewer for a few days per year. They cannot usually be burned since the sodium content causes slagging difficulties in the boilers.

Many mills now collect pulp spills caused by equipment failures and dump them to landfill rather than to sewer as in the past. The total quantities can be significant, say 30 tonnes in one day, but are generally quite small on an annual basis.

5.4 Sulphite Pulping

The species usually pulped by this process are spruce, fir, balsam and western hemlock. Birch and poplar are among the few hardwood species used. The dwindling availability of suitable wood species, the rising cost of wood and high effluent treatment costs have been major reasons for the declining popularity of this pulping process. The sulphite pulp can be classified according to the commercial use in the following way:

- unbleached sulphite for newsprint and other low colour products;
- bleached sulphite grades for bond, ledger, white printing, and writing grades; and
- dissolving sulphite grades used in the manufacture of rayon, acetate yarns, and film.

5.4.1 Basic Sulphite Process. A simplified flowsheet of a sulphite system is presented in Figure 19. The cooking liquor is prepared by burning sulphur to produce SO_2, or occasionally purchasing liquid SO_2, and then absorbing this in an alkaline base solution. In the past, limestone was used exclusively in the gas absorption tower, serving both as a packing and a chemical source of calcium to produce calcium bisulphite. In recent years, the use of soluble bases such as magnesium, sodium, and ammonium have largely replaced the use of limestone because of the opportunities for increased pulping yields, for environmental reasons, and for the improved strength qualities of the pulps produced. For soluble bases, inert packing such as berl saddles, etc., are used in the absorption tower. The raw cooking acid is a mixture of free SO_2 dissolved in water and combined SO_2 in the form of Ca, Mg, NH_4, or Na bisulphite depending on the base used. Before the raw acid is used in pulping it is fortified with relief SO_2 from the digester. This fortification takes place in the low and high pressure accumulators, which are pressurised to increase the solubility of sulphur dioxide in the liquor. Typical acid strengths and the degree of fortification are presented in Table 7 for the acid sulphite process.

TABLE 7 SULPHITE LIQUOR ANALYSIS

	% by weight	
	Raw acid	Digester Acid
Total SO_2	4.0 - 4.2	5.0 - 8.0
Free SO_2	2.8 - 2.5	5.0 - 6.8
Combined SO_2	1.2 - 1.7	1.0 - 1.2

The traditional calcium base process utilises a pH of about 1.5 in the digester, which is designated an acid sulphite condition. The soluble bases that have become more popular in recent years normally use liquor with a pH from 2 to 5, which is commonly designated bisulphite cooking.

The gases leaving the low pressure accumulator are usually scrubbed with an alkaline base to further recover any SO_2 not absorbed by the raw acid in the accumulator. In the digester, temperature and pressure must be carefully controlled to ensure uniform penetration of the cooking liquor. Delignification is accomplished by sulphonation and hydrolysis reactions which form soluble ligno-sulphonates. Before discharging the pulp,

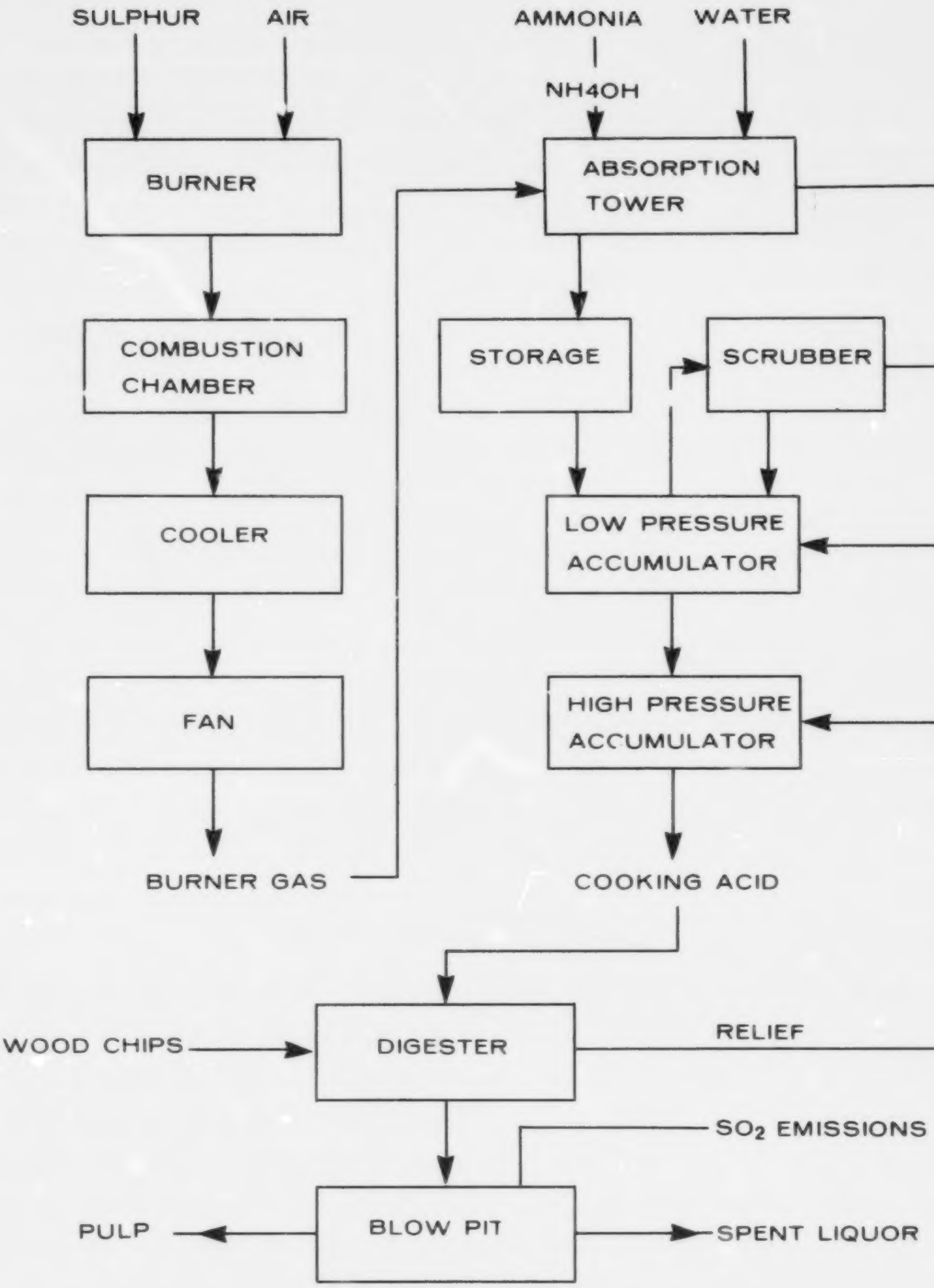
SULPHUR
AIR
BURNER
COMBUSTION CHAMBER
COOLER
FAN
BURNER GAS
AMMONIA
NH4OH
WATER
ABSORPTION TOWER
STORAGE
SCRUBBER
LOW PRESSURE ACCUMULATOR
HIGH PRESSURE ACCUMULATOR
COOKING ACID
WOOD CHIPS
DIGESTER
RELIEF
SO_2 EMISSIONS
PULP
BLOW PIT
SPENT LIQUOR

FIGURE 19 SULPHITE PULPING PROCESS

the pressure is reduced with the steam and digester gases being relieved to the accumulators. The pulp is discharged by opening the blow valve at the bottom of the digester while some pressure remains, so that the stock is blown to either a blow pit or a blow tank.

A blowpit is a tank with a finely perforated bottom to allow liquids to drain out while retaining the pulp. The spent cooking liquors are drained to sewer and the pulp washed by successive rinsing with white water and/or fresh water. This is very effective in removing dissolved chemicals from the pulp but they are very dilute, rendering recovery impractical.

A blow tank is an atmospheric cyclone similar to the kraft blow tank described previously. It is usually connected to a drum washer system similar to the kraft brownstock washing system. The terms blow tank and blow pit are often used interchangably.

5.4.2 High Yield Sulphite Pulping. An increasingly popular variation of the conventional sulphite pulping process described above is to partially cook the chips in a digester and complete the defibering action in refiners, similar to those described in Section 5.1. This is practical only if a soluble base is used, and most of the high yield processes use sodium base.

The pulp is most often used for newsprint and similar grades, and in the extreme case the high yield sulphite process becomes more akin to mechanical pulping with some chemical assistance. In such cases it is generally known as chemimechanical pulp, often abbreviated as CMP. There is no absolute division between the types, but 80% yield is commonly accepted as the upper limit for "high yield sulphite". Generally as the yield rises the chemical consumption drops and the refining power required rises.

5.4.3 Composition of Spent Sulphite Liquor. Rydholm summarised the by-products of a typical low yield cook, as shown in Table 8. He also gives some indication of product origin from the various wood components as well as relative quantities produced per tonne of pulp. As expected the major products are those derived from degradation of the hemicelluloses and lignin. A number of useful products have been produced from sulphite spent liquors. These include acetic acid, formic acid, alcohols, vanillin, torula yeast, cement dispersants, and road binders. Unfortunately the market for such products is very limited.

Spent liquor composition varies with wood species, yield, pulping conditions, etc. In the strongest spent liquor (i.e., directly from the blowpit) residual total SO_2 levels

TABLE 8 BY-PRODUCTS OF A TYPICAL SULPHITE COOK*

Compound	Origin	Quantity (kg/tonne pulp)
Methanol	Methoxyl groups of the glucuronoxylan	7-10
Acetic acid	Acetyl groups of the xylan	30-90
Formic acid	Bisulphite oxidation of formaldehyde	0.5-1
Formaldehyde	Hydroxymethyl groups of lignin	2-6
Methyl Glyoxal	Degradation of hexoses	5-6
Furfural	Dehydration of pentoses	5-6
Sugarsulphonic and aldonic acids	Bisulphite substitution and oxidation of sugars	150-250
Sugars	Hemicellulose and cellulose	200-400
Cymene	Bisulphite oxidation of terpenes	0.3-1
Lignosulphonates	Lignin	600-800

*S.A. Rydholm, Pulping Processes, Interscience Publishers, 1965.

typically range from 0.2 to 0.5% while pH can vary from 1.5 to 5 depending on the base used. The solids content of undiluted spent sulphite liquor is usually in the 7 to 14% range. About 50% of the residual solids are organic, the remainder being inorganic. By-product recovery removes up to about 60% of the BOD from the spent sulphite liquor but also reduces the organic content, rendering conventional chemical recovery more difficult.

5.4.4 **Effluents.** The total flow of effluent from a sulphite pulp mill without recovery varies widely with values from 50 to 200 m^3/t being reported. Note that the effluent from other departments must be added to estimate the total flow from a complete pulp and paper mill or market pulp mill.

The suspended solids content of the effluent is normally quite low, typically under 2 kg/t pulp.

TABLE 9 TYPICAL SULPHITE WASTE LIQUOR CHARACTERISTICS

	Quantity (kg/t)		
Chemical Group	48% yield	60% yield	70% yield
Lignosulphonic Acid	650	550	400
Fermentable Sugars	150	75	25
Nonfermentable Sugars	50	40	25
Sodium	125	100	80
Sulphur	140	115	90
Miscellaneous Inorganic	25	25	15
Total	1140	905	635
BOD_5	300	240	140

The BOD content of the effluent depends on the yield, the washing efficiency, and whether there is a chemical recovery system. The values in Table 9 are typical if there is no chemical recovery system.

The toxicity of the sulphite pulping effluents varies widely depending on the base used. The ammonia content in effluents from ammonium base mills causes additional toxicity to that due to the organics present.

The obvious method of reducing the effluent BOD and toxicity is to raise the pulping yield. This normally requires the installation of refining power to take over some of the the defibering from the digester and has been the approach practiced by many Canadian sulphite mills. In the case of sulphite mills with recovery operations, any increase in pulp washing efficiency reduces the BOD and toxicity in the effluent, assuming that the recovery system has the capacity to burn the additional solids recovered.

Reduction of suspended solids losses can be achieved by the methods discussed for kraft pulp mills in Section 5.3.4.

5.4.5 Atmospheric Emission Sources and Control. Sulphur dioxide and sulphur trioxide are normally emitted from the absorption tower used to prepare the cooking acid. Typical values for the total sulphur oxide emissions are as follows.

Calcium base	10-20 kg/t
Magnesium base	3-10 kg/t

Ammonium base	1-10	kg/t
Sodium base	1-5	kg/t

Where very low pH acid is required by process, the emissions will be at the high end of the range. Except in the case of calcium base mills, the emission pH can be reduced by extending the absorption tower and by careful burner control. In calcium base mills the only effective control measure may be the installation of a separate alkali scrubber.

The only emission of significance that occurs during the cooking process is the sulphur dioxide discharged during the cooking and when the digester is discharged during the blow. The digester relief during the cooking operation is normally well controlled by a completely contained system of pressure vessels (accumulators) between the digester and the acid plant. During the blowing of acid sulphite digesters, up to 75 kg/t sulphur dioxide may be emitted into the atmosphere with the steam. The sulphur dioxide discharges for the bisulphite and high yield processes are much lower.

If the digester is dumped, that is the digester contents are washed from the digester with wash liquor after the pressure has been reduced to zero in the digester, rather than blown at an elevated pressure, the emissions are significantly reduced.

Many mills have separate blow tanks, or pits, and emission stacks (generally known as vomit stacks) for each digester. In some sulphite plants it is practical to install adequate water showers in the blow tank vents to control the blowing emissions. Alternatively, emission control may require a scrubber, by means of which the emissions can be controlled to less than 5 kg/t pulp.

5.5 Semichemical Pulping

Semichemical pulping normally refers to processes with yields between about 60% and 80%. Strictly speaking the high yield variants of the sulphite process discussed above would be in the semichemical category, but they are normally described as high yield sulphite pulps.

Semichemical pulping methods were initially developed to accommodate the large quantities of hardwood species that were not being used. The primary uses for such pulps have been in corrugating media and for certain writing and printing papers because of the rigidity and stiffness they provide.

Semichemical pulping is a two-stage process. The chipped wood is first treated chemically in a digester followed by a mechanical defibrating stage in a disc refiner. Semichemical pulp yields vary depending on the end-use of the pulp and the extent of the chemical treatment. A considerable portion of the lignin (10 - 18%) remains in the final pulp. The hemicellulose content also remains high at 18 - 20% for hardwood and 8 - 10% for softwoods.

A simplified flow sheet of the process is shown in Figure 20. The two major semichemical pulping processes in use are the neutral sulphite and the kraft-semichemical.

5.5.1 Neutral Sulphite Semichemical Pulp. In the neutral sulphite semichemical process, abbreviated NSSC, delignification occurs by lignin sulphonation and hydrolysis. The main cooking agent is sodium sulphite. Buffering of the liquor is also carried out to prevent alkalinity and acidity from degrading the hemicelluloses. This is usually accomplished by the addition of sodium carbonate to the cooking liquor. While buffering preserves most of the hemicelluloses, it retards delignification, but to a lesser degree. When about half the lignin is dissolved delignification tends to slow down considerably. The cook is blown at this point and pulping is completed using mechanical disc refiners.

The spent cooking liquor from the process presents problems for disposal to receiving waters because of its organic acid content. Because these liquors are low in organic and high in inorganic content relative to lower yield pulping liquors, the application of conventional recovery employing evaporation and combustion proved impractical until the 1960's. The introduction of fluidized-bed reactors has permitted combustion of these spent liquors after preconcentration to 30 - 35% solids, although the economics are often unfavourable. The inorganic chemicals and sodium organic salts are chiefly oxidized to sodium sulphate and sodium carbonate pellets. This material is removed from the reactor and can be sold to a kraft mill for use as its chemical make-up, if a suitable market exists.

Another acceptable method of disposing of NSSC spent liquor is to deliver it directly to a conventional kraft recovery system. This technique is known as cross recovery. In such an instance the close proximity of the kraft mill is essential. However cross recovery is feasible only to the extent permitted by the chemical losses of the kraft mill. With older kraft mills, the ratio between kraft and NSSC production would typically be 3 to 6:1, but the chemical losses in some modern kraft mills are sometimes so low that cross recovery is impractical.

5.5.2 Kraft Semichemical Pulp. Kraft semichemical (KSC) pulping has the advantage of being applicable to hardwoods or softwoods. The yields are less than for NSSC pulping and are normally around 65 - 70%. KSC liquor is a weak white liquor

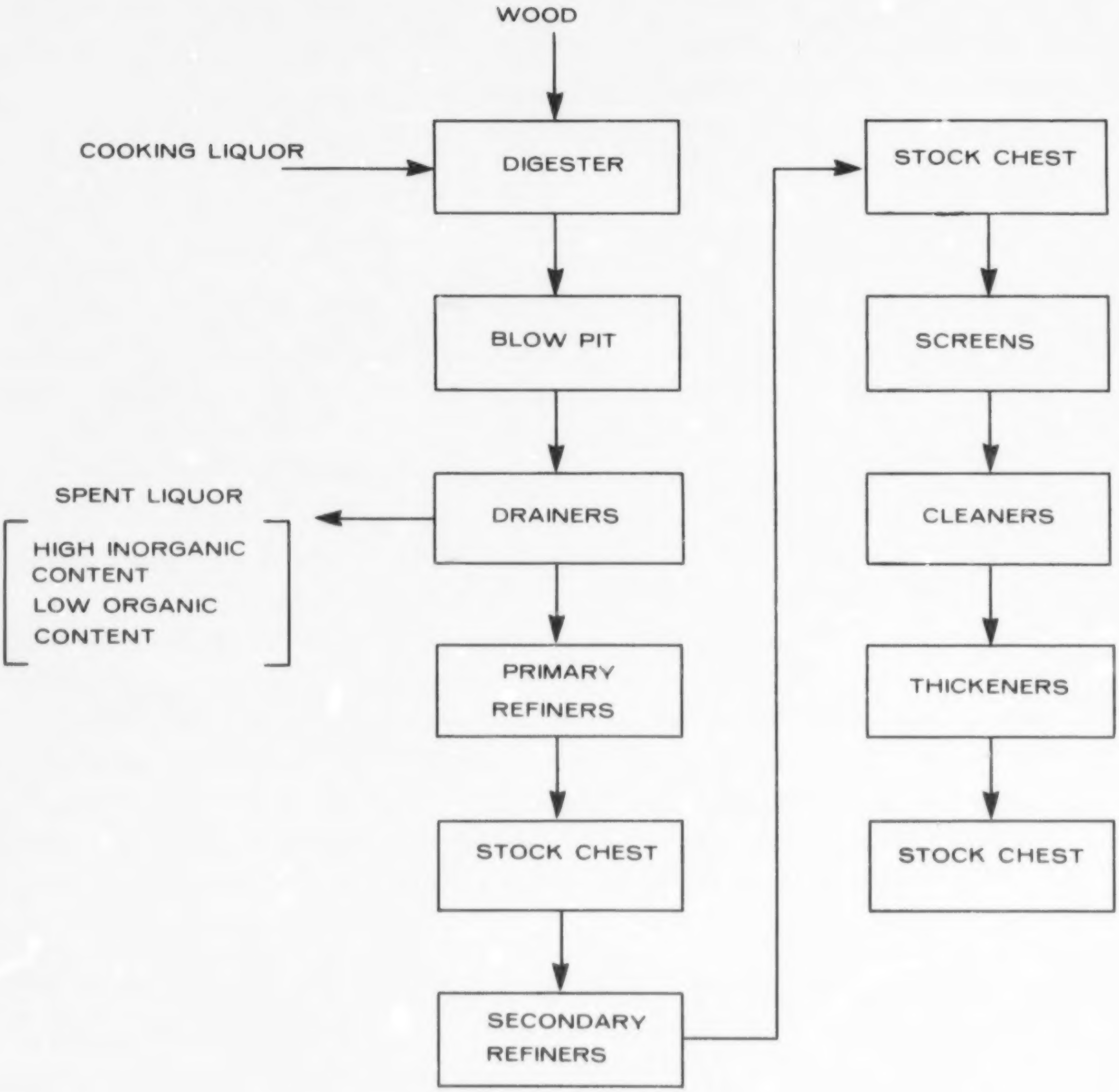
WOOD
COOKING LIQUOR
DIGESTER
BLOW PIT
SPENT LIQUOR
HIGH INORGANIC CONTENT
LOW ORGANIC CONTENT
DRAINERS
PRIMARY REFINERS
STOCK CHEST
SECONDARY REFINERS
STOCK CHEST
SCREENS
CLEANERS
THICKENERS
STOCK CHEST

FIGURE 20 SEMICHEMICAL PULPING SYSTEM

normally obtained from an associated kraft mill. Cooking time is usually less than 30 minutes for temperatures of 170 - 180°C. Mechanical refining is the same as NSSC while the spent KSC liquor is combined with the kraft recovery system of the associated plant. The close proximity of a standard kraft mill is essential for economic operation of a KSC system, although the limit on capacity ratio mentioned above for NSSC cross recovery does not exist.

5.5.3 **Effluents.** Semichemical pulp is always used on-site for the production of paper in an integrated mill. In some cases the pulp is washed by pressing as much as possible of the spent cooking liquor out in a screw press, and there is a small fibre loss from this equipment, typically under 0.1 kg/t pulp. The principal effluent is the spent liquor. The press effluent itself contains about 15% dissolved solids, with a BOD of about 40 kg/t pulp. Most of the remaining BOD is washed out of the pulp in the paper machine and appears in the white water at a concentration of several hundred mg/L. If there is no washing of the pulp, then all the BOD appears in the paper machine white water, and is discharged to sewer with the excess white water.

If the mill has a chemical recovery system, then all the BOD removed from the pulp stream in the press (or other washing equipment) is routed to the chemical recovery system where it is mostly destroyed. Refer to the discussion of chemical recovery systems in Section 11.

A characteristic of corrugating medium, which is the normal product of NSSC pulp mills, is that it can tolerate much higher dirt and dissolved solids than most paper products. This allows the closure of many water cycles which cannot be effectively closed in other pulping processes. The result is that most of the BOD is concentrated in the press filtrate and can either be sent to a recovery system, or used for road binder in some cases, avoiding discharge to sewer. A closed cycle NSSC mill need only discharge 5 kg BOD/t pulp while in normal operation. An additional BOD discharge of 2 - 20 kg/t occurs due to accidental spills.

5.5.4 **Atmospheric Emissions.** There is an emission of SO_2 from the digester vent, and from the cooking acid preparation plant. However, due to the high pH of the system, the SO_2 emission is normally minor or negligible.

6 PULP SCREENING AND CLEANING

Screening and cleaning systems are installed in various parts of the mill for the removal of undesirable materials from the pulp or paper stock. In a pulp mill, there is usually a screening system to remove incompletely pulped wood and fibre bundles. In chemical pulp mills, the screens usually follow the pulp washers, while in mechanical pulp mills, the screens are immediately downstream of the grinders or refiners as applicable. In paper mills, there is normally some screening and cleaning equipment installed in the stock preparation area and many market kraft mills screen and clean the bleached pulp immediately prior to drying it.

The objective of pulp screening and cleaning is to remove dirt and foreign matter such as slivers, knots, grit, bark, sand, uncooked chips, etc., from the pulp. This is usually accomplished by:

- coarse screening, also called bull screening or deknotting,
- fine screening, and
- centrifugal cleaning operations.

In most instances, coarse screening preceeds washing, and fine screening follows washing.

The fine particles of dirt, grit and other unacceptable matter are removed by centrifugal cleaners. The fine screening and/or cleaning operations may be included after bleaching or in the stock preparation area immediately upstream of the paper machine. The detailed design and operation varies in such cases, but the principles remain identical and the equipment is similar.

Generally screens identify and remove impurities from the pulp on the basis of size, whereas centrifugal cleaners rely on principally differences in specific gravity to effect separation.

6.1 Coarse Screening

Coarse screening is used to remove oversized material such as knots, slivers, and unground pieces of wood. The screens usually have openings of 5 to 10 mm in size and may be of the vibratory mechanical, open rotary, and centrifugal rotary types.

In groundwood operations the most common coarse screens are the inclined scraper screen, the vibratory screen, the rotary screen and the bar screen. This stage is generally known as the bull-screen.

In chemical pulping operations the vibratory screen used to be the conventional knotter although the use of sealed centrifugal rotary screens (pressure knotters) is now widespread, and is virtually universal in new mills.

6.2 Fine Screening

Fine screening is used to remove the fibre bundles and particles that are 4 to 20 times larger than the average whereas coarse screening removes debris that is about 90 times larger. Because complete classification cannot be attained by one pass through the primary screens, secondary, and tertiary screens are employed. The use of the vibratory flat screen for this application gave way to the compact, free-discharge, open centrifugal "Cowan" screen in the 1950s and 1960s. In the 1970s closed pressure screens started to replace the open screens and most new installations use these screens.

The current terminology is confusing. A closed screen is one which operates under pressure with no free liquid surface. To the chemical engineer a closed screen room operates without effluent. Many modern screen rooms have "closed" screens but have substantial effluent flows. In this manual the term "pressure screen" will be used for the equipment.

A typical modern pressure screen is depicted in Figure 21. A block diagram of a typical mechanical screening system was presented earlier in Figure 8, during the discussion on mechanical pulping. It was shown to be a tightly closed system with waste discharges mainly coming from the tertiary cleaner rejects.

A flow sheet for a typical chemical pulp screening system is given in Figure 22. As with the mechanical pulp system, the major wastes are from the tertiary cleaners and the excess filtrate from the thickening deckers which cannot be re-used for dilution water in various parts of the system.

Modern screens normally operate best at consistencies from about 1 to 2%.

6.3 Cleaning

The centrifugal cleaner is the most common device used in pulp cleaning to remove bark, sand, grit and other small particles. An illustration of a centrifugal cleaner is presented in Figure 23. Separation is effected mainly by the difference in specific gravity between the debris and acceptable pulp.

Dilute pulp is fed tangentially into the conical separator body causing a rapid spinning of the pulp and a downward movement in the cone. Small surface area particles and high specific gravity debris migrate to the walls of the cone, move downward and

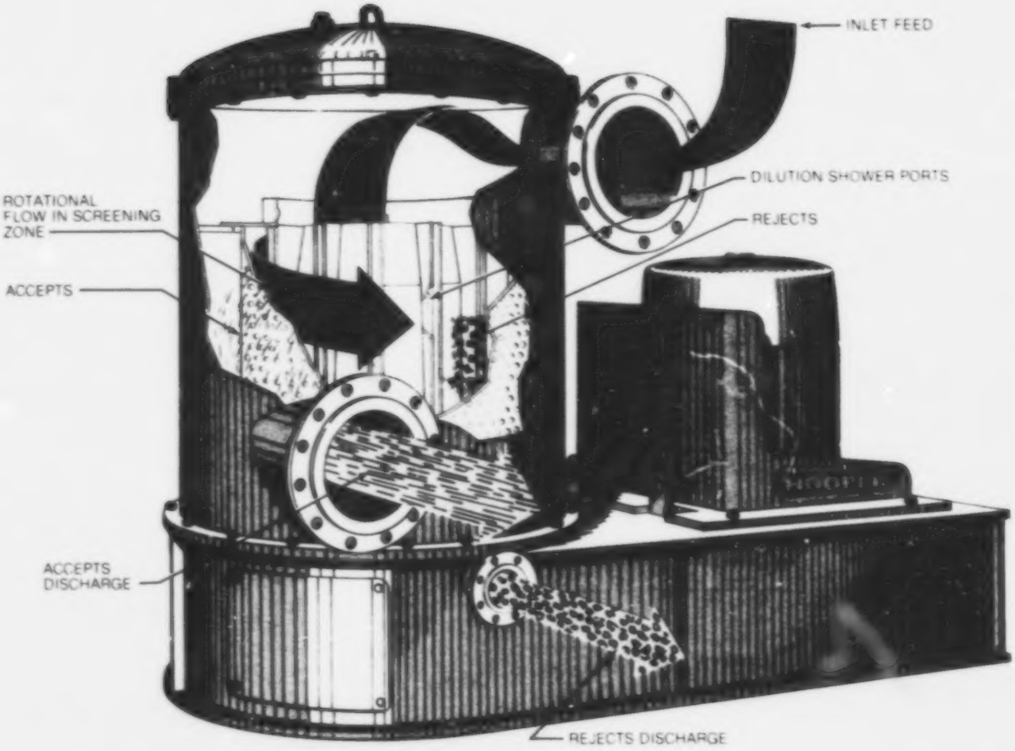
INLET FEED
DILUTION SHOWER PORTS
REJECTS
ROTATIONAL FLOW IN SCREENING ZONE
ACCEPTS
ACCEPTS DISCHARGE
REJECTS DISCHARGE

FIGURE 21 PRESSURE SCREEN

converge into the purge outlet. The upward vortex created in the centre of the cone carries the lighter, cleaner fibers to the accepts discharge.

Secondary and tertiary stages are employed to clean the rejects from the preceding cleaning stages, hence recovering most of the usual fibre. Many mills have the cleaning operation following coarse screening while others have it after fine screening operations.

Centrifugal cleaners normally operate at consistencies from about 0.5% to 1%, which complicates any cleaning before fine screening since the screens operate at higher consistency, requiring a dewatering process.

6.4 Thickening

After screening and/or cleaning the pulp is usually thickened or dewatered from about 0.5% consistency to 3 to 14% depending on usage and storage requirements. This economises on storage capacity requirements and minimizes the influence of shutdowns in various parts of the system. If continual blending of the pulp in storage is

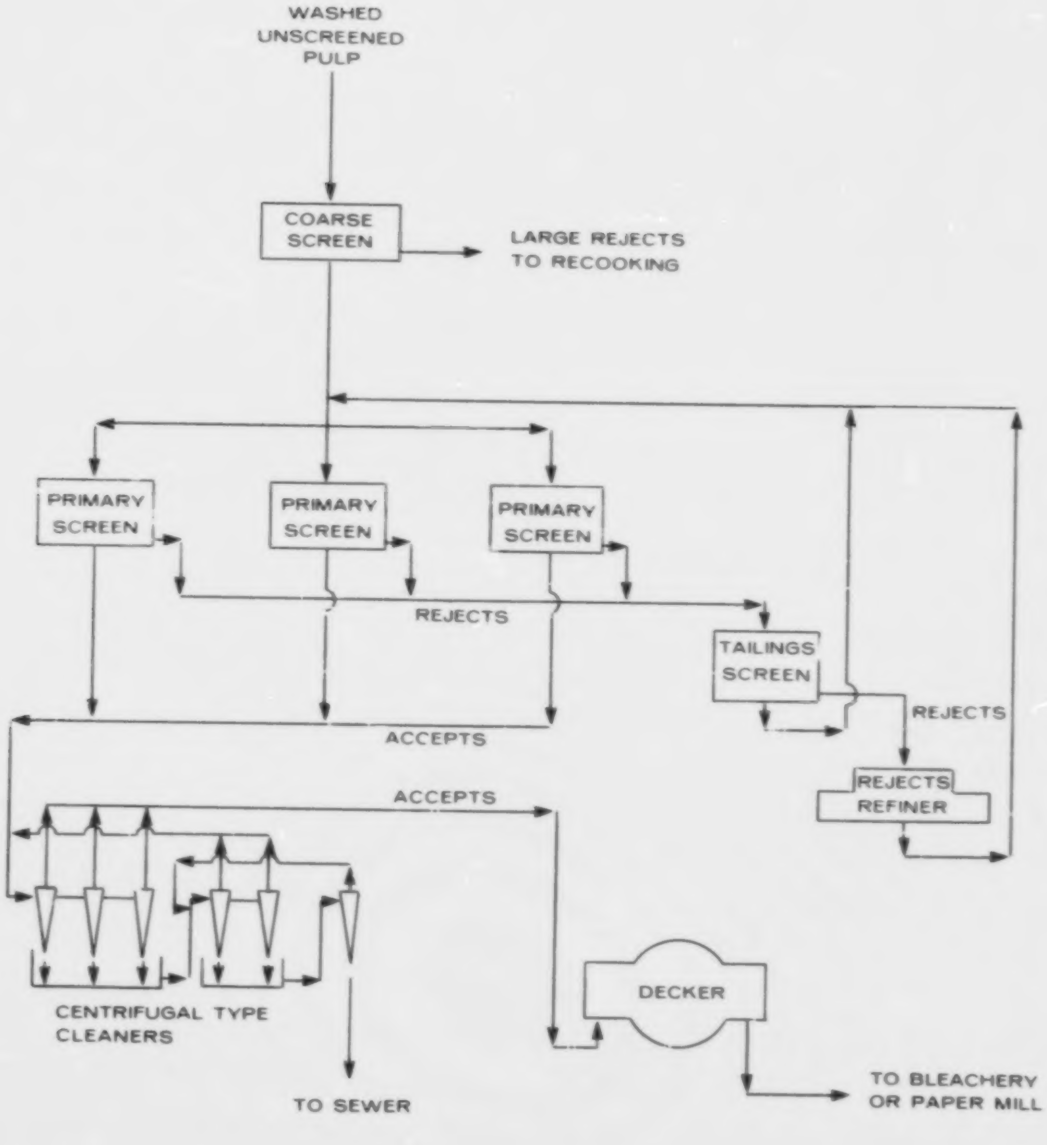
WASHED UNSCREENED PULP
COARSE SCREEN
LARGE REJECTS TO RECOOKING
PRIMARY SCREEN
PRIMARY SCREEN
PRIMARY SCREEN
REJECTS
TAILINGS SCREEN
REJECTS
ACCEPTS
ACCEPTS
REJECTS REFINER
CENTRIFUGAL TYPE CLEANERS
DECKER
TO SEWER
TO BLEACHERY OR PAPER MILL

FIGURE 22 CHEMICAL PULP SCREENING AND CLEANING SYSTEM

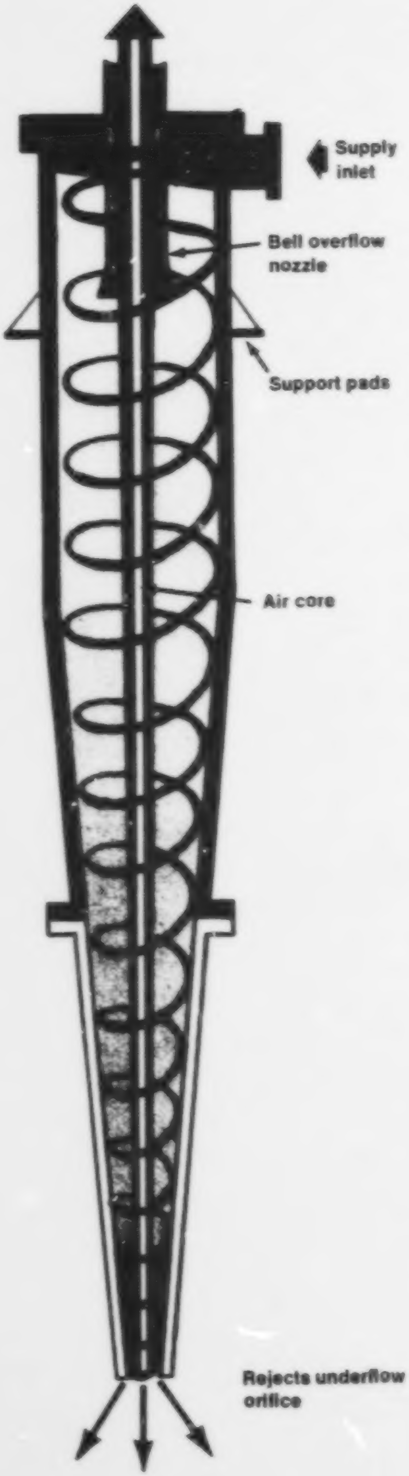
Supply inlet
Bell overflow nozzle
Support pads
Air core
Rejects underflow orifice

FIGURE 23 CENTRIFUGAL CLEANER (Bauer)

desirable the thickened consistency should not be over 4%. When blending is not a requirement and storage is to be maximised, then the consistency would be about 12%. The water removed on thickening is usually returned for re-use in washing and screening, or perhaps elsewhere, or it is sewered.

The thickeners used are either gravity deckers or vacuum filters. Such dewatering operations may be employed after pulp washing, after fine screening, as well as before and after bleaching.

The decker or gravity thickener will thicken pulp to a range of 4 to 8% consistency. It consists essentially of a vat for diluting pulp and a wire-cloth covered cylinder to dewater the pulp. The pulp level in the vat is maintained about half a metre below the top of the cylinder while the water level in the cylinder is kept low to increase the gravity head flow which effects the flow of water into the cylinder and hence the pulp mat build-up on its surface.

The vacuum filter used for thickening is similar to that described previously for pulp washing in Section 5.3.2. Consistencies of 10 to 20% can be achieved. The advantages of vacuum filters over deckers are the reduced floor area requirements, reduced fibre losses and lower maintenance. A typical drum type unit is illustrated in Figure 24. In some cases the vacuum is obtained using a vacuum pump.

For slow draining stock such as mechanical pulp or papermaking furnishes, most installations since about 1970 have used a disc filter. These operate on the same principle as the vacuum drum described above, but have the filtration media distributed over several parallel discs on a common shaft. They are more complicated than drum filters, but can usually be designed to give greater filtrate clarity.

In many mills, any device used to thicken the pulp after the screening is called a decker, whether it is gravity or vacuum operated.

6.5 Washing in Screen Room

In the case of kraft mills and also those few sulphite mills with chemical recovery systems, there is an obvious possibility of using the screening, cleaning and thickening system as an additional washing stage.

The successive dilution and thickening operations in a screen room, combined with the retention time of many minutes and the mechanical action of the screens, transfer dissolved organic material from the fibres to the white water. Traditionally, screen rooms used substantial quantities of make-up water, washing the pulp very

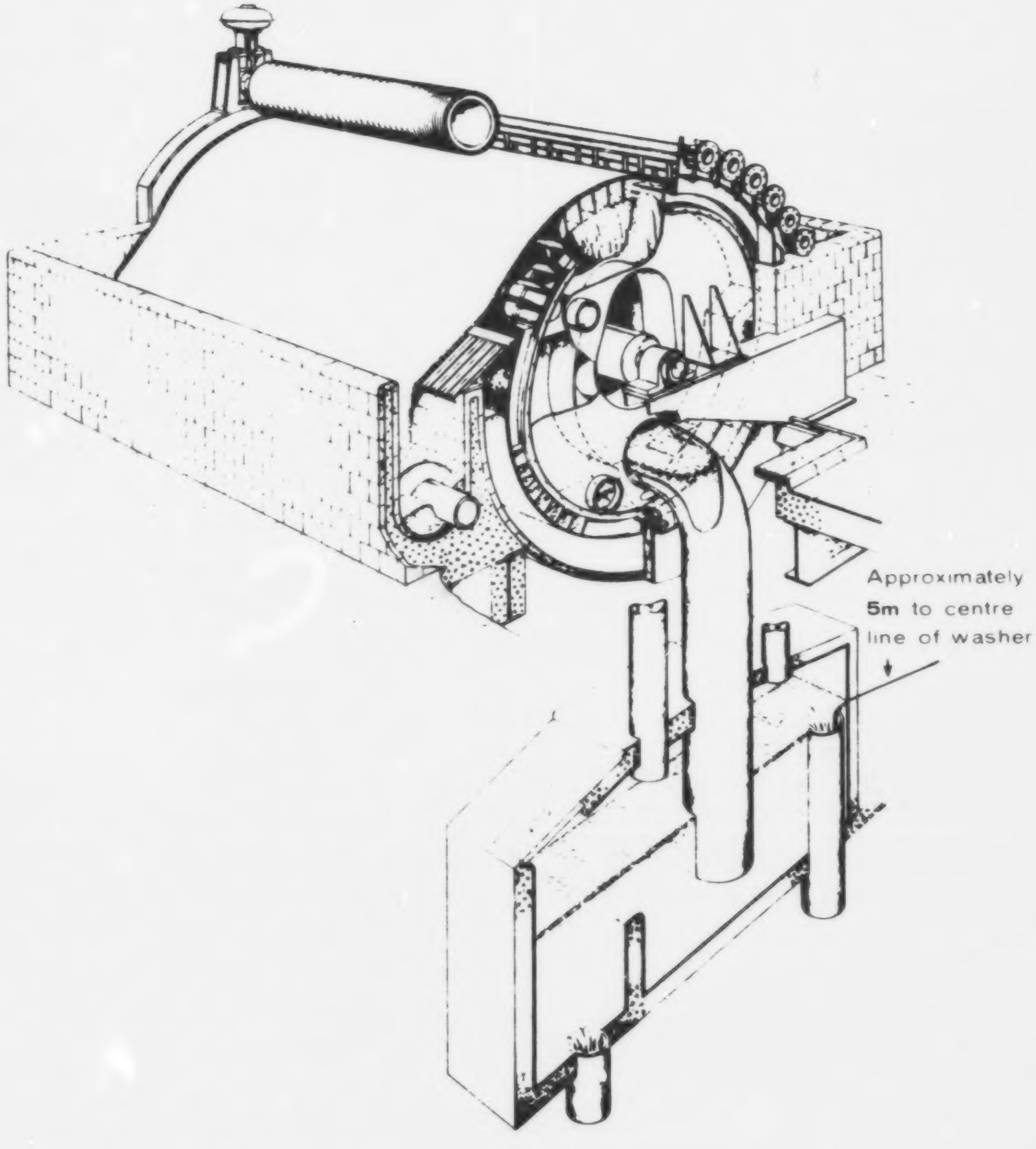
Approximately
5m to centre
line of washer

FIGURE 24 VACUUM DRUM FILTER

thoroughly prior to any bleaching and giving rise to large white water flows to sewer (described as unbleached white water in much of the literature).

If the make-up flow could be reduced to correspond to the shower water flow required for the pulp washers, then there would be no screen room effluent (except for rejects which could be dumped to landfill in relatively dry form) and the organic material, with the spent cooking chemicals, would all be returned to the chemical recovery plant. However, there are many practical difficulties in such an approach and until the late 1970s relatively few mills operated closed-cycle screen rooms. Environmental considerations have advanced closed-cycle screening because it is a prerequisite for oxygen bleaching and the Rapson-Reeve closed-cycle kraft process.

Foaming in the screen room is a major problem in kraft mills, and the operator's only solution in most cases is to use sufficient dilution water to lower dissolved solids concentrations to a level where the quantity of foam formed is acceptable. High washing efficiency prior to screening removes much of the residual black liquor and reduces the formation of foam in the screen room, facilitating system closure. Modern screening systems using pressure screens and having sufficiently large tankage to allow entrained air to separate effectively from the stock and white water are better adapted to system closure. Stock from diffusion washing is less inclined to foam than that from drum washers, since the latter cause air entrapment. Also, wood species is an important factor in the extent of foaming. Additions of chemical defoamer provide a partial solution but are expensive.

If the pulp is not adequately washed prior to screening, a closed screen room process would cause high bleach chemical consumption and possibly increase the toxicity of the mill effluent by raising the concentration of chlorinated lignin compounds discharged. Figure 15 indicates that complete closure of the screen room water cycle has the same effect on BOD losses to sewer as adding a fourth washing stage. This is typical, although the exact effect will vary slightly. In many cases, four washing stages prior to screening are necessary to avoid excessive foam formation.

6.6 Effluents and Solid Wastes

In a survey of kraft mills by the Alkaline Pulping Committee of the Technical Section, Canadian Pulp and Paper Association (CPPA), fibre rejects were reported from 1 to 5 kg/t production for a range of kraft mills. For a 600 tpd mill this would range from 1 to 3 tonnes per day. Water balance data for brownstock screening and cleaning indicates:

-	fresh water usage	3.3 - 23 m^3/ODt
-	bleach white water usage	1.2 - 8 m^3/ODt
-	unbleached white water usage	15 - 10 m^3/ODt
-	sewered water	0.8 -16 m^3/ODt

More recent data would indicate a modest reduction on these values, particularly for recently constructed mills.

In the case of mechanical pulp mills, the screen rejects are almost always refined and recovered, since they consist primarily of partially pulped wood. Cleaner rejects vary from about 2 to 10 kg/t pulp and may be sewered or dewatered for landfill or incineration.

In other types of mills, screen rejects may be sewered or dumped to landfill and typically amount to a few kg/t pulp. Cleaner rejects are generally heavily contaminated with sand and other non-fibrous material and cannot be recycled. They are usually sewered but may also be dewatered and landfilled. The quantity depends very much on the cleanliness of the wood or waste paper furnish and can vary from 1 kg/t to as much as 30 kg/t pulp in extreme cases. Where cleaner rejects contain substantial amounts of fibre, either an improvement in operating procedures or, more often, better cleaning equipment is usually desirable.

6.7 Atmospheric Emissions

The vents from the thickener and its seal tank contain very small quantities of TRS in kraft mills, and are sometimes connected to the brown stock washer odour control system. There are no other significant atmospheric emissions from the screen room.

7 BLEACHING

The pulps produced by either mechanical or chemical pulping methods are a colour ranging anywhere from a dark brown to a creamish white depending on the wood type and the defibering process used. While much of the pulp produced is used in its unbleached state for cardboard boxes, bags, newsprint, coarse papers, and the like, over half of it is bleached to produce white paper products. Bleaching is the removal or alteration of those light absorbing substances present in unbleached pulp.

The main light absorbing substances in wood pulp are derived from the lignin, resin, metal ions, and non-carbohydrate components of the original woods. Cellulose and the hemicelluloses contribute no colour as they are inherently white. Lignin derivatives are the major colour constituents in the pulp. It is generally believed that, during chemical pulping, light absorbing complexes are formed from the phenolic groups of the lignin and give rise to the darkened colour of the pulp produced relative to the original wood. Many complex factors contribute to the relatively minor brightness loss during grinding and refining in the mechanical pulping process.

In the past, bleaching was confined mainly to chemical pulps but in recent years high-yield mechanical pulps are also being bleached to meet rising product standards.

7.1 Brightness Measurement

When a surface has the ability to fully and diffusely reflect all colours in the same proportion as they are contained in sunlight, the reflector is said to be pure white (such as a block of magnesium oxide). Absorption of one or more wavelengths will produce observable colour changes. The assessment and comparison of brightness levels requires the definition of a measuring system, a reference standard, and suitable testing equipment.

Standard Brightness in the industry has been arbitrarily chosen to be the reflectance observed from a sample when illuminated with a light wavelength of 457 nm and backed by an opaque layer of its own kind. Reflection in the blue region of the spectrum (457 nm) was originally chosen for brightness because, of all the single-value measures of whiteness potential of the final product, blue reflectance is the most sensitive and relevant.

The two major reflectance photometers in use today are:

- the General Electric Brightness Meter, and
- the Elrepho photoelectric reflectance photometer.

Because of its optical geometry, the Elrepho is much less dependent on sheet surface than the GE unit and thus does not require strict adherence to sheet-making procedures. The difference in brightness values obtained using these two meters are usually only a few percent. This is of little importance in general discussions such as this manual but is often very significant in particular cases.

7.2 Mechanical Pulp Bleaching

The brightness requirements of mechanical pulp applications are not as great as chemical pulps and generally range from 60 to 75 GE brightness. The brightness of unbleached groundwood pulps usually ranges from 50 to 65 GE brightness depending on the operating conditions and wood species used. Spruce and balsam fir are best with brightness of 58 to 64 GE, jack pine ranges from 55 to 59 GE and western hemlock is in the 51 to 56 GE range.

In bleaching mechanical pulp the objective is chiefly to decolourise the pulp without solubilizing the lignin. This is usually accomplished with either reducing or oxidising agents. Both provide similar brightness increases although brightness reversion from reductive bleaching is greater than from oxidative bleaching. Table 10 illustrates the brightness increases expected from various bleaching agents. The hydrosulphites are the most commonly used brightening agents.

Peroxides are excellent bleaching agents whenever high brightness is required but are more expensive than hydrosulphites. The two-stage peroxide-hydrosulphite process possesses the greatest bleaching potential but is expensive.

The yield losses from mechanical pulp bleaching are likely to be under 1% depending on the conditions and chemicals used. This dissolved material is chiefly in the form of organic matter and adds to the mill's BOD loading. In some extreme cases where extensive brightness improvement is required, yield losses could be up to 4%, which could add up to about 25 kg BOD/t pulp to the mill effluent.

The use of zinc hydrosulphite for bleaching has been banned by some environmental authorities and it is no longer used in Canada as zinc is a heavy metal and tends to accumulate in fish.

TABLE 10 BLEACHING PROCESSES FOR MECHANICAL PULPS

Bleaching Process	Usual Method of Application	Brightness increase, G.E. Units
Reducing		
Sodium bisulphite	Applied at grinders or to chips before refining	1 - 4
Sodium hydrosulphite	Added to pulp before entering tower or storage chest	3 - 6
Zinc hydrosulphite	Not environmentally acceptable	
Sodium borohydride	Not used commercially	-
SO_2-Borol	Added in sequence to pulp before storage chest	10
Oxidizing		
Calcium hypochlorite Sodium hypochlorite	Limited to hardwoods, added ahead of storage chest	10 -12
Hydrogen peroxide	Usually in tower process sometime on wet machine	10 -14
Sodium peroxide Peracetic acid	Not used commercially	10
Combined		
Peroxide-hydrosulphite	Tower Process	12 -18

7.3 Chemical Pulp Bleaching

The bleaching of chemical pulps is often considered an extension of delignification which commenced in the digestion stage. The initial brightness of unbleached kraft pulps is about 20 while that for unbleached sulphite pulp is around 60. It is thus more difficult to bleach kraft pulp to a given brightness level. Sulphite pulps can be bleached to high brightness (90+) with a three-stage bleaching sequence of chlorination, caustic extraction and hypochlorite bleaching, whereas normal kraft pulp processes usually employ a five or six-stage sequence to achieve the same brightness.

7.3.1 Conventional Bleaching. There are many variations of chemical pulp bleaching; the following describes a representative case:

- A Chlorination Stage (C) where the addition of Cl_2 to the pulp solubilizes most of the residual lignin through substitution and addition reactions. The chlorinated pulp is then washed and thickened before entering the alkaline extraction stage. About one-third of the chlorinated lignin products are removed by washing. This chlorination washer filtrate has a high BOD content and considerable quantities of coloured chlorolignin compounds. It is normal practice to sewer this filtrate.
- Alkaline Extraction Stage (E). This stage involves the addition of sodium hydroxide to the pulp to remove the residual reaction products that were incompletely solubilized in the acidic aqueous phase of the chlorination stage but become readily dissolved in alkaline medium. Alkaline treatment of pulp also removes resinous materials, pentosans, and other low molecular weight carbohydrates. Mild alkali treatments do not influence papermaking qualities of the pulp. Alkaline extraction is employed after each intermediate oxidative bleaching stage and is followed by thickening and washing of the pulp. The filtrate from the first extraction stage is very high in dissolved colour constituents as well as being the most toxic stream from a kraft bleaching system. Normal practice is to sewer the washer filtrate from the first extraction stage.
- Other oxidative bleaching stages. At least one oxidative bleaching stage is required following chlorination and extraction to yield a commercially bright pulp. Sodium hypochlorite (H) and chlorine dioxide (D) are the most commonly used oxidative bleaching chemicals.

Sulphite pulps after a C (chlorination) and E (extraction) stage have a brightness of about 70 which can usually be raised easily to 90 with one additional oxidative stage.

With kraft pulps the starting brightness level after C and E stages is about 30 and three or more additional stages are required to reach a 90 brightness. A CEHEH sequence on a kraft pulp will yield about an 85 brightness. The discovery of chlorine dioxide's potential as a bleaching agent around 1946 permitted kraft pulps to be bleached to 90+ brightness levels without strength loss. Two of the most common kraft bleaching sequences employed today are CEDED and CEHDED.

A flow diagram of a typical five-stage bleach plant is given in Figure 25. The flow diagram also illustrates the two types of water recirculation used in a bleach plant.

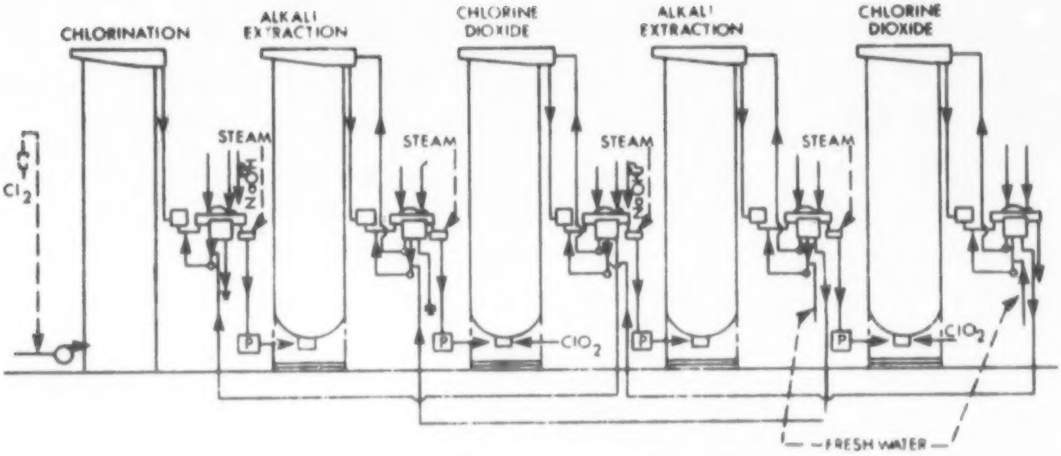
CHLORINATION
ALKALI EXTRACTION
CHLORINE DIOXIDE
ALKALI EXTRACTION
CHLORINE DIOXIDE
STEAM
STEAM
STEAM
STEAM
Cl_2
NaOH
NaOH
P
P
P
P
ClO_2
ClO_2
FRESH WATER

FIGURE 25 FLOW DIAGRAM OF A FIVE-STAGE BLEACH PLANT (CEDED) (TAPPI Monograph 27)

Within the individual stage, the filtrate from the washer seal box can be re-used to dilute and convey the stock going to that same washer. This represents an extremely large amount of filtrate (typically 100 m^3/t pulp), but since it is an internal recycle, the water demand from outside the system is minimal. The other recycle method involves the transfer of excess filtrate from the final washer seal boxes to earlier stages thus maintaining a countercurrent flow of filtrate from the bleached end towards the unbleached end of the plant. The use of fresh water or white water in the showers assures that the sheet going into each bleaching stage will be relatively free of dissolved organic matter which would otherwise consume bleaching chemicals. For maximum water conservation in terms of traditional bleaching technology, only the overflow from the chlorination and first caustic extraction stages is sewered.

7.3.2 Effluents from Conventional Bleach Plants. A 1970 water survey of kraft mills by the Alkaline Pulping Committee of the CPPA indicated wide variability in sewered filtrates from the different plants. The approximate ranges for the various streams were:

Unbleached white water	3 - 14	m^3/t
First chlorination filtrate	22 - 62	m^3/t
First caustic extraction filtrate	7 - 17	m^3/t

In a Cooperative Pollution Abatement Research (CPAR) survey in the early 70's on "Water Re-Use and Recycle in Bleacheries", by J. Histed (available from Environment Canada), the lowest effluent volume from a conventional five-stage bleach plant was 30 m^3/t, not including effluent from the unbleached decker. A number of the lowest effluent conventional technology bleacheries in North America today employ full countercurrent washing and have effluent volumes down to about 25 m^3/t. Major additions of fresh or white water are usually applied to the showers of the final bleach stage washers and to the first showers of the chlorination washer while minor amounts are added on the showers of intermediate stages. A similar study today would generate a comparable range of data but would indicate that many more mills were near the lower flows quoted than ten years previously.

In the early seventies, environmental pressures stimulated a number of extensive investigations directed at determining composition, BOD, COD, colour and toxicity of bleach plant effluents. Evidence has shown that in most mills the most toxic process stream is the wash filtrate from the first caustic extraction stage, followed by the unbleached decker filtrate, the chlorination effluent and the combined mill outfall in descending order of toxicity. Data from a study of seven kraft mills over a 40-day period reported in CPAR Project Report 10-1 ranked the effluent streams for both toxicity and BOD_5 as indicated in Table 11.

TABLE 11 TYPICAL BLEACHED KRAFT MILL EFFLUENT CHARACTERISTICS

	Median Survival Time (minutes)	BOD_5 (mg/L)
First caustic extraction filtrate	136	235
Unbleached decker filtrate	207	227
Chlorination effluent	449	155
Combined mill outfall	728	195

The MST values quoted refer to the median survival time until death of 50% of the coho salmon exposed to 100% concentrations of the various effluents. All toxicity measurements were made on air-stripped, filtered and neutralized samples. The dissolved oxygen content of the samples was maintained at saturation to ensure that the cause of death was the toxicity of the non-volatile effluent constituents and not oxygen depletion.

While ranking the toxicity and BOD of the various effluents, the study also showed that there was considerable variability between the mills sampled and within individual mills. This is not surprising in view of the range of woods and process variations, as well as in the flows of effluent. At the time of the survey many mills had no means of determining accurate flows. It was also shown that knowledge of BOD does not permit prediction of the probable toxicity of a given sample. Discharges were found to range from 10 700 kg to 33 700 kg BOD/d corresponding to 17.5 - 47 kg BOD/ADT pulp produced.

Bleach plant effluents are toxic to fish, and in most kraft mills are the most important single source of effluent toxicity. Since the toxicity guideline in the federal regulations is based on concentration, there has been a tendancy for the toxicity of modern bleach plant effluents to be higher than some older installations which use very large amounts of fresh water resulting in high effluent flows.

The bleach plant is usually the principal source of the dark brown colour which is characteristic of bleached pulp mill effluents. The caustic extraction stage effluent is normally the most significant by far, and colour from 20 000 to 50 000 APHA units is typical. The screen room effluent (frequently known as unbleached white water), recovery plant and kraft pulp mill sewers can also be significant colour sources if the pulp washing is poor or if there are frequent spills of black liquor.

7.3.3 Process Variations on Conventional Bleaching. Various modifications to the basic kraft bleaching processes described above have been proposed, with the objective of improving the effluent quality.

Chlorine dioxide substitution, which has been widely adopted, is the partial substitution of chlorine in the first stage by chlorine dioxide. This has been claimed to substantially reduce the toxicity of bleach plant effluents and in some cases to reduce the colour and BOD slightly. However, there is considerable variation in the results obtained in different mills.

Increased use of sodium or calcium hypochlorite appears to reduce effluent colour, and some mill trials conducted by MacMillan Bloedell in the early 1970's indicated that an 80% reduction in colour could be achieved, although at increased chemical cost. The applicability of this and similar process modifications is mill specific, since wood species and brownstock washing efficiency have a major impact.

7.3.4 Displacement Bleaching. In displacement bleaching chemicals in solutions and wash water move through pulp at 8 to 10% consistency in a direction transverse to the continuous movement of the pulp. The equipment is similar to the diffusion washers described in the brownstock washing section. Most of the process is installed in a single displacement bleaching tower, decreasing water consumption by eliminating interstage dilution and substantially reducing bleach plant space requirements. About a dozen such plants are operating, but none in Canada.

Displacement bleaching is, in effect, an equipment variation on the conventional process in that it does not produce any real reductions in BOD, COD, colour or organic discharge, although it renders them more manageable by reducing the effluent volumes substantially. Effluent volumes as low as 10 m^3/t have been reported, but most displacement bleach plants discharge about 15 m^3 effluent/t pulp.

7.3.5 Oxygen Bleaching. This innovation, developed in the late 1960s, involves the elimination of the first two conventional bleaching stages of chlorination and caustic extraction. It consists of treating the pulp with oxygen under pressure, in an alkaline medium. About half of the COD, BOD, and colour is in the oxygen stage effluent which is chloride free, so that the final discharge can be greatly reduced, providing that the effluents are introduced to the kraft recovery cycle. Comparing the OCEDED sequence with the CEHDED sequence the following reductions have been achieved:

BOD_5 is reduced by	50%
COD is reduced by	40%
Colour is reduced by	60%

The actual reduction in any one case depends on the degree of delignification in the oxygen stage and may in some cases be lower, either by design or due to equipment limitations. At the time of writing, there are several oxygen bleach system operating world-wide, including two in Canada.

7.3.6 Papribleach Process. This process is based on the application of ammonia to chemical pulps at consistencies of 20 - 40% in a fluffed state. Laboratory Papribleach sequences of $C_gED_gED_g$ (where g indicates gas phase) produced bleached pulps which match or exceed those obtained by the conventional CEDED sequence. Laboratory work in the early 1970s indicated that a $C_gNH_3D_gNH_3D_g$ sequence could reduce the cost of chemicals and steam by $3 to $5 per tonne over that of the conventional CEDED sequence. Mechanical properties of the pulps produced equalled or surpassed those of conventional bleaching methods. There have, however, been no commercial installations to date.

7.3.7 Closed-Cycle Bleaching. The ultimate method of handling bleach plant effluent is to use it as dilution and wash water in the recovery system. However, before this can be achieved, the volume of effluent produced must be reduced to below 20 m^3/t for evaporation of the resulting weak black liquor to become economically feasible. Closed-cycle bleaching is discussed further in Section 14.

7.3.8 Atmospheric Emissions. The only emissions of potential significance from the bleaching operation are chlorine and chlorine dioxide from the bleach towers, seal tanks and washer hoods (Table 12). Emissions from the chlorine dioxide generators may be significant, especially if the absorption tower is inadequately sized. This emission is sometimes controlled with scrubbers using caustic as scrubbing medium. Limited data are available on the actual emissions. For the remainder of the bleach plant, emission levels are not well documented but are considered small except for upset conditions.

TABLE 12 BLEACH PLANT ATMOSPHERIC EMISSIONS*

	kg/ADt pulp	
	Cl_2	ClO_2
Total Bleach Plant		
Number of mills reporting	6	6
Average	0.5	0.15
Maximum	2.4	0.25
Minimum	0.005	0.0003
Chlorine Dioxide Generators		
Number of mills reporting	4	4
Average	0.2	0.12
Maximum	0.75	0.39
Minimum	trace	trace

*Data as reported to Environment Canada 1974 and published in Report EPS 3-AP-77-6.

8 STOCK PREPARATION

Stock preparation is the term used to cover those papermaking operations involving:

- repulping and blending of different pulps,
- the addition of various chemicals and fillers, and
- the mechanical treatment necessary to make fibres suitable for forming into a sheet of paper.

Support functions also include consistency regulation, proportioning, beating, refining, machine chest mixing and screening.

In paper mills that purchase all or part of their pulp, the stock preparation department is the first stage of production. In these mills pulpers are installed which are essentially vigorously agitated vessels where dry pulp or waste paper is mixed with water and discharged at a controlled consistency, typically about 3%.

8.1 Furnish

The furnish or pulp mixture going to a paper machine varies widely depending on the grade of paper being made. For example, newsprint was formerly always a mixture of 75 to 80% groundwood pulp and 25 to 20% chemical pulp, usually with no chemical additives, although the current trend is to include up to 100% TMP with little or no chemical pulp. On the other hand, bond paper can be 100% sulphite pulp or a combination of sulphite and rag pulp or sulphite and kraft; it usually contains 4 to 10% filler and a starch surface sizing application. The number of different paper types is so large and they are so different in their make-up and end use that it is impractical to describe them all in this manual. Many of the publication grades are a blend of fibres and inorganic fillers. Sack and linerboard grades usually have a high proportion of kraft, often 100%. Tissue is normally predominantly kraft or a mixture of kraft and waste paper furnish.

To demonstrate the wide variation in grades of paper and boards manufactured, a short list is given below:

Printing Grades
Banknote
Bible
Blotting, filter
Bond, ledgers

Industrial Grades
Bag, wrapping, liner
Carbonizing
Cigarette tissue, condenser tissue
Construction paper and board

Book
Light weight boards
Cover, drawing
Data processing
Duplicating
Wall paper stock
Newsprint, catalogue
Offset
Photographic
Stationery, envelope
Food packaging
Gumming and label
Insulating papers
Paperboard
Sanitary tissues

A typical continuous stock preparation system is shown in Figure 26. The proper proportions of the various pulps forming the furnish are first added in a blending chest. If required, dyes, size, fillers, alum, etc., are also added and mixed thoroughly at this point. The furnish is then pumped to a machine chest where the consistency is carefully controlled through the use of automatic consistency regulators. The stock is then fed to the suction of the fan pump, which recycles large volumes of white water from the wire pit back to the headbox, along with the new stock. Any mechanical fibrillation of the pulp fibres is usually carried out in a disc refiner or similar equipment prior to the pulp reaching the paper machine, following the stuff box.

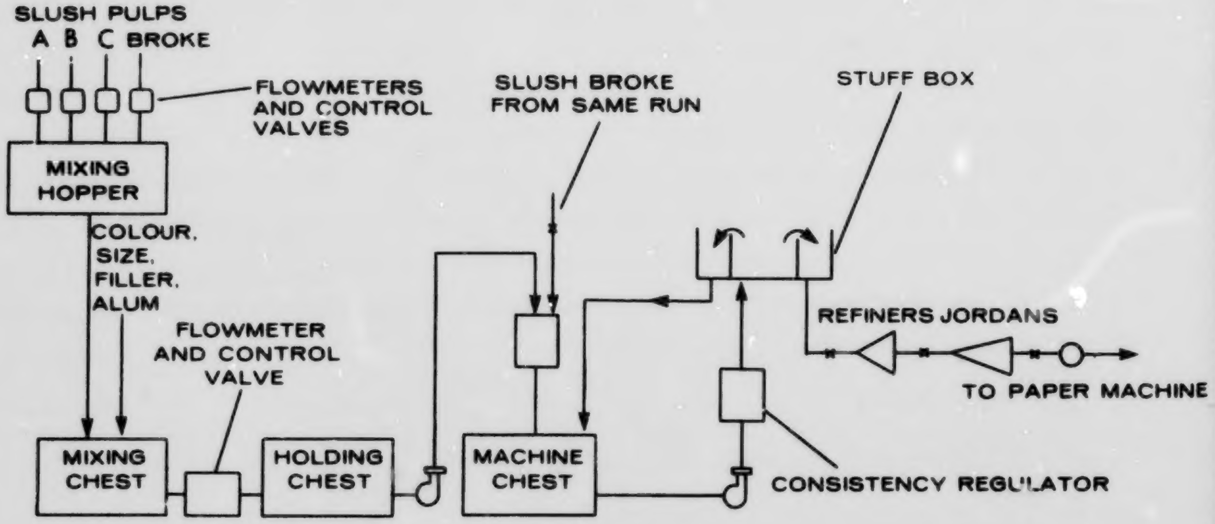
SLUSH PULPS
A B C BROKE
FLOWMETERS AND CONTROL VALVES
SLUSH BROKE FROM SAME RUN
STUFF BOX
MIXING HOPPER
COLOUR, SIZE, FILLER, ALUM
FLOWMETER AND CONTROL VALVE
REFINERS JORDANS
TO PAPER MACHINE
MIXING CHEST
HOLDING CHEST
MACHINE CHEST
CONSISTENCY REGULATOR

FIGURE 26 STOCK PREPARATION SYSTEM

8.2 Stock Refining

Mechanical fibrillation or refining of the pulp fibres is a vital part of the papermaking process. It refers to the use of mechanical devices which act on the fibres to give them increased surface area, greater flexibility and fibrillated surfaces. Such action substantially increases the strength properties of the paper produced as well as making it more uniform, more opaque and less porous.

The traditional device used for mechanical treatment of the pulp fibres was the Hollander beater although they are now little used. It consisted of an oval shaped tub, a beater roll equipped with metal bars or blades and a stationary bedplate. The fibres passed repeatedly between the roller blades and the bedplate where they were mechanically treated to develop the surface and improve the bonding characteristics.

Other traditional devices used for mechanical treatment of the pulp fibres include the Jordan, and the conical refiner. Such devices are known as continuous refiners and are employed just prior to the pulp reaching the paper machine. They can be used alone or in combination with each other, depending on the desired properties of the paper being produced. Because refiners function on continuous basis, they have largely replaced the older style beater. The double disc type, shown in Figure 27, is the predominant modern design.

These disc refiners are identical in principle to the refiners used in mechanical pulping but are normally much smaller, being driven by motors of a few hundred kW rather than the several thousand kW units one finds in many mechanical pulp mills.

8.3 Additives

Fillers are usually included with the furnish to give the paper increased opacity, brightness and smoothness. These materials are usually fine grained powders such as clay, talc, diatomite, gypsum, calcium carbonate, calcium sulphate, titanium dioxide, and barium sulphate. They can be added in slurry form in the blending operation. Only a portion of the filler added is retained in the sheet; the remainder is recirculated in the white water system. Spillage or sewering of such white water causes loss of the filler and an effluent high in suspended solids.

Sizing of the pulp is a further treatment commonly given to the stock to provide wet strength, improved printability and resistance of the paper surface to damage due to the pull of the ink in printing. This property is known as pick resistance. Materials used include rosin size, natural waxes, starches, glues, synthetic resins, and latexes. They

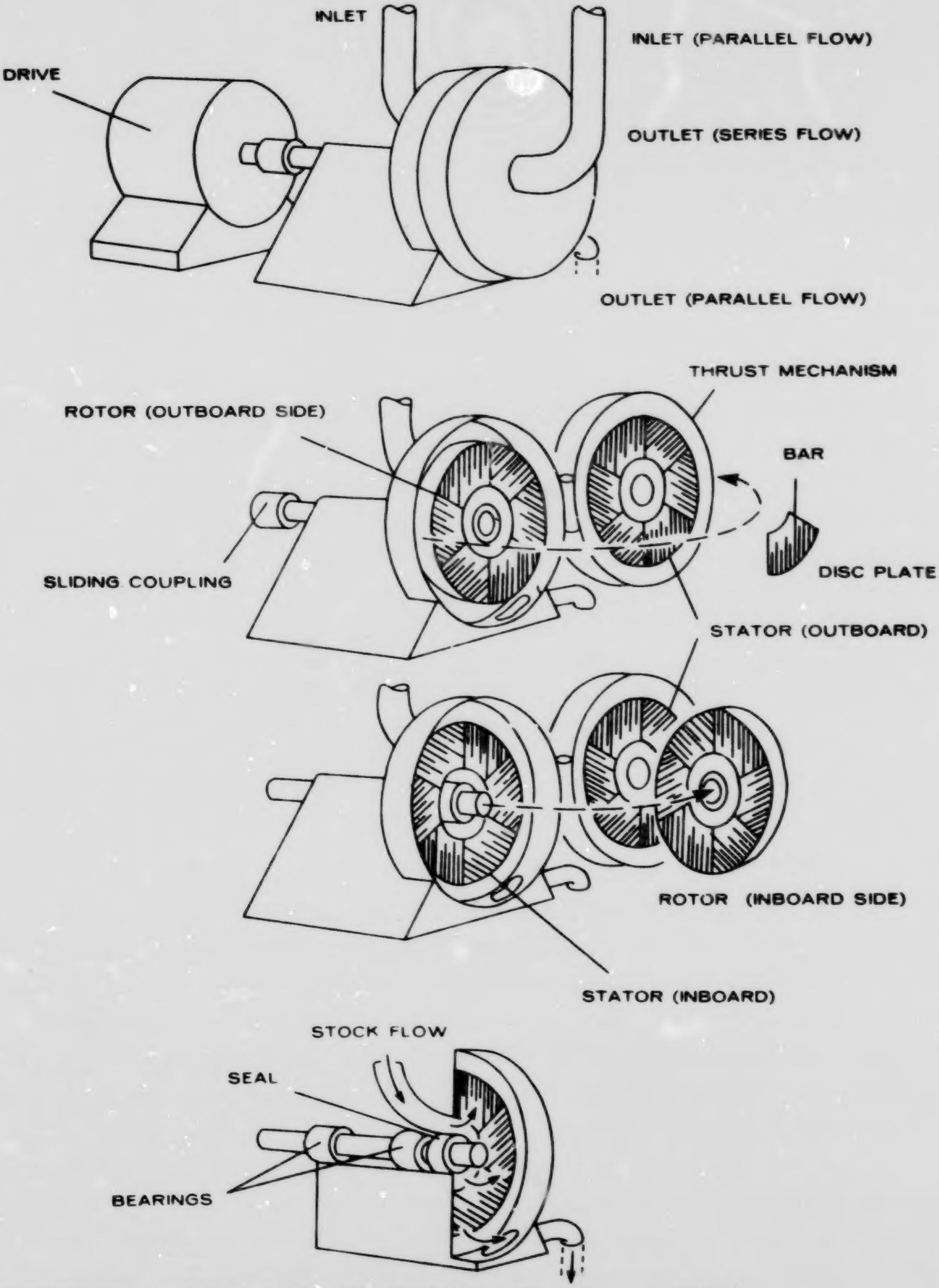
INLET
INLET (PARALLEL FLOW)
DRIVE
OUTLET (SERIES FLOW)
OUTLET (PARALLEL FLOW)
THRUST MECHANISM
ROTOR (OUTBOARD SIDE)
BAR
SLIDING COUPLING
DISC PLATE
STATOR (OUTBOARD)
ROTOR (INBOARD SIDE)
STATOR (INBOARD)
STOCK FLOW
SEAL
BEARINGS

FIGURE 27 DOUBLE DISC REFINER (Simplified Representation)

are usually added to the pulp in the blending or beating stage and later precipitated onto the fibres by alum (or sodium aluminate) addition just prior to the pulp reaching the paper machine. An alternative method of sizing, referred to as surface sizing, is to run the partially dried sheet through a sizing solution.

Colouring dyes are often included in the furnish to produce the desired sheet colour. Such dyes or pigments are added in the beater or other points ahead of the paper machine. They are generally divided into two broad groups: 1) synthetic organic dyes and 2) synthetic, natural and inorganic dyes. Synthetic organic dyes are most commonly applied and are usually classified as acid, basic, direct or sulphur type dyes.

8.4 Screening and Cleaning

Most stock preparation areas include some cleaning and screening equipment similar to that described in Section 6 of this manual. In this case, the stock is fed directly to the paper machine from the primary cleaners without use of a decker.

8.5 De-inking

A small proportion of the waste paper recovered in Canada is used for the production of tissue and printing grades, which necessitates the removal of virtually all the impurities.

After pulping and removal of gross contamination, surfactants are added to the slurried waste paper to separate the ink from the fibres. The objective is to disperse the ink in very small particles which have minimal affinity for the fibres, so that the two can be separated, either by washing or by flotation.

The washing approach is the most common in North America. It is based on the fact that the very fine ink particles behave rather like dissolved solids if the pulp is successively diluted with water and rethickened, providing that the formation of a pulp fibre mat is avoided in the thickening equipment. Several stages of washing are used, necessitating the use of substantial quantities of water. The filtrate contains the ink etc. removed from the waste paper, and it is resistant to conventional primary treatment techniques because of the dispersants mentioned above. Extensive coagulant addition is required to remove the suspended matter from the wastewater.

In the flotation process, the ink particles are separated from the pulp fibres by introducing air into the pulp slurry which adheres to the ink and causes it to float as a froth, which is relatively easily removed. This process generates much less wastewater than washing the ink out of the pulp, so is gaining in popularity.

8.6 Effluents

Cleaner and screen rejects can be up to few percent of total production but are normally under 1%. It is not possible to define an "acceptable" rate of suspended solids discharge since it depends on the product specifications, and the cleanliness of the pulp furnish, which can range from high grade bleached kraft to heavily contaminated waste paper.

In most cases it is feasible to dewater the rejects and landfill them instead of discharging them to sewer. However, if the mill has a primary clarifier with adequate sludge handling equipment, it may be more economical to discharge these rejects to sewer so that they will be recovered in the clarifier. If the ash content of the rejects is low, they can be burned in a bark boiler. However, a low ash content generally implies a high fibre content, and suggests that the better way of reducing the suspended solids discharge would be to improve the cleaning system so that it can provide acceptable quality stock with a reject low in fibre.

White water losses are considered in the paper machine section.

If there is no screening or cleaning system, there will theoretically be no effluent from a stock preparation area of a mill during steady state operation.

The BOD discharge is generally negligible, unless there are significant starch leaks or other losses due to equipment weaknesses. Good housekeeping is the prime control measure.

8.7 Atmospheric Emissions and Solid Waste

There are no significant atmospheric emissions or solid waste from stock preparation departments.

9 PAPER MACHINES AND PULP DRYERS

The paper machine is the mechanical system used to convert the pulp suspension into paper. All paper machines consist of a wet-end or forming section, a press section, and a dryer section. The most common wet end machines in use are:

- the Fourdrinier,
- the twin wire former, and
- the cylinder machine.

The Fourdrinier paper machine is the most common device used today and has been successfully adapted to make a wide range of papers and light weight boards and may also be designed for pulp drying. During the 1970s twin wire formers which improve paper quality and sometimes production capacity became increasingly popular and are now widely used. Cylinder machines are chiefly used to produce heavy papers, paperboard and non-uniform paper. Press sections use felt blankets to remove further water from the web, as the full width of paper on the machine is called. The dryer uses heated cylinders and hot air to remove the remaining water from the web to the level required in the final product, whether paper or pulp.

9.1 Fourdrinier

The principle components of a modern Fourdrinier are illustrated in Figure 28. The route of the web or paper sheet through the machine is also illustrated.

The pulp suspension enters the headbox at about a 0.5% consistency (depending on the grade being made) and flows out through the slice opening onto a travelling Fourdrinier wire screen. Most of the water flows through the wire by gravity and by the suction action of the hydrofoils, table rolls and suction boxes. The white water withdrawn in the vicinity of the headbox, foils and table rolls is rich in fibres, fines, fillers, etc. which pass through the wire, and is collected separately from the leaner white water removed by the suction boxes and the couch roll. The rich white water goes to the wire pit where it is recycled to dilute the thick stock coming from the machine chest. The leaner white waters on the other hand, go to a different compartment called the couch pit. This water is used as stock dilution while excess flows to a saveall collection pit. The actual split between lean and rich white water flows depends on the water balance requirements of each paper machine.

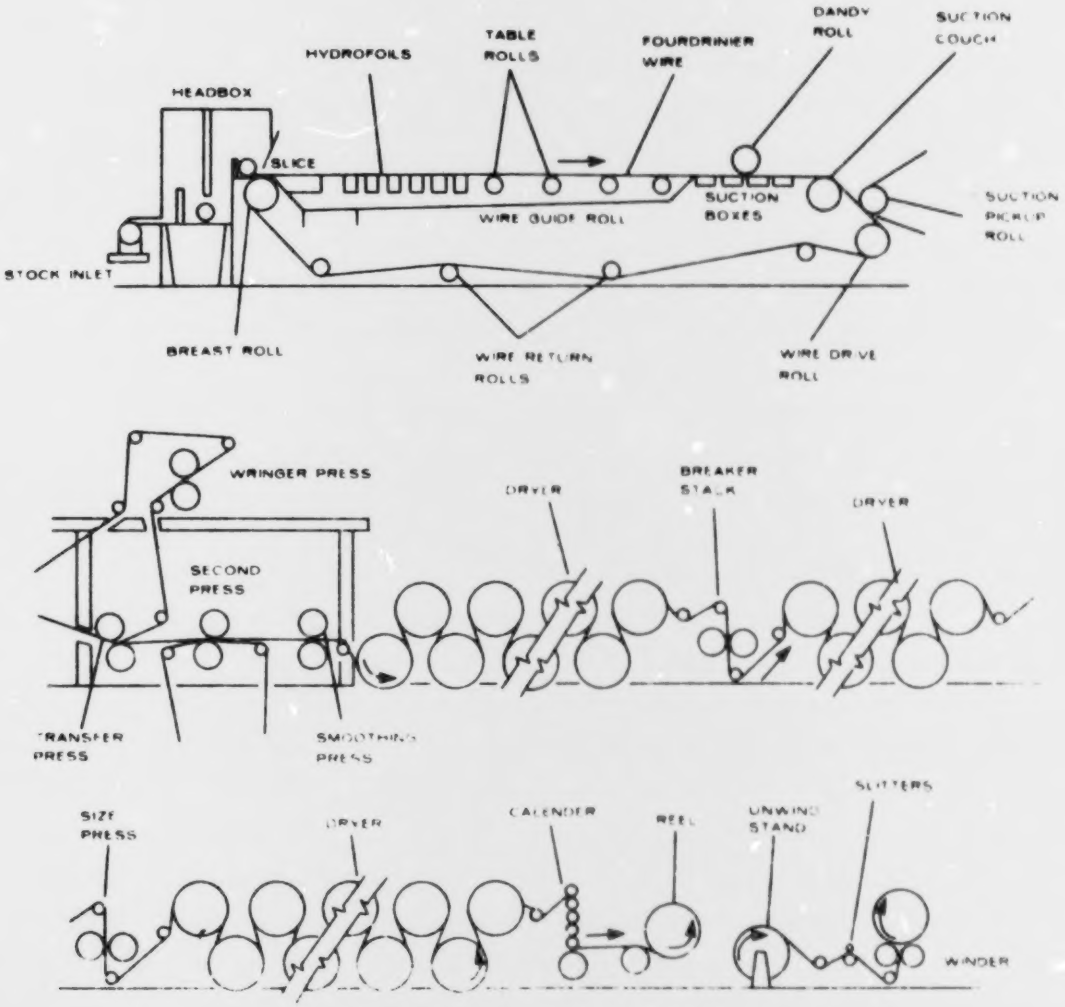
HEADBOX
HYDROFOILS
TABLE ROLLS
FOURDRINIER WIRE
DANDY ROLL
SUCTION COUCH
SLICE
SUCTION BOXES
WIRE GUIDE ROLL
SUCTION PICKUP ROLL
STOCK INLET
BREAST ROLL
WIRE RETURN ROLLS
WIRE DRIVE ROLL
WRINGER PRESS
DRYER
BREAKER STACK
DRYER
SECOND PRESS
TRANSFER PRESS
SMOOTHING PRESS
SLITTERS
SIZE PRESS
DRYER
CALENDER
REEL
UNWIND STAND
WINDER

FIGURE 28 FOURDRINIER PAPER MACHINE

Woven plastic mesh has largely replaced metal mesh for the Fourdrinier "wire", but the terms wire or plastic wire are universally used.

After the suction boxes and suction couch roll, the web has a consistency of about 15 to 22%. It is then transferred from the wire to a pickup felt or first press felt by a suction pickup roll and enters the press section where additional moisture removal is achieved. The web is subsequently transferred to the second press felt where further water is removed by pressing the web and felt blanket together in the second press. Some machines also have a third press. The last press could be either a straight-through smoothing press as shown in Figure 28 or a reverse press. The smoothing press imparts smoothness to the wet web prior to entering the drying section ensuring good contact with dryer drum surface. The web attains a consistency between 30 to 45% before leaving the press section.

The dryer section normally consists of a series of steam drying rolls over which the paper is led by a dryer fabric. The dryer fabric or felt also holds the wet web against the drum to assure optimum heat transfer. The drying sections of the machines are enclosed with dryer hoods and vents for removal of the moisture-laden air as drying takes place. The dryer hoods are not shown in Figure 28. Some machines are also equipped with a breaker stack located about two-thirds of the way down the main dryer section. Its function is to compact and smooth the web while it still has fairly high moisture content. The size press is shown in Figure 28 after the main dryer section; sizing solutions such as starch can be added to the surface of the web giving the paper improved printing properties and resistance to liquid penetration. The web is usually quite dry, between 4 and 12% moisture content, before entering the size press. After sizing, a further drying section is required to remove moisture absorbed in sizing. Newsprint is normally not sized. In fine paper production the size press might be replaced by an on-machine coater, depending on the grade being made.

The dried web enters the calender stack where it is compressed and given a smoothed surface prior to reeling. When a reel is full it is transferred to a rewinder equipped with slitters which cut the paper into roll sizes to suit the customer.

Operating speeds of Fourdrinier machines typically vary from 10 to 500 m/min for fine paper production through 1100 m/min for newsprint and up towards 2000 m/min for tissue.

In the past the coating of paper was usually carried out in an independent operation because the coater ran at much lower speeds than the paper machines. Today most medium quality coated papers are coated on the paper machine. Off-machine coaters are used particularly where heavy coating weights are needed or where other conditions exist which do not permit application on the paper machine without slowing it down.

Off-quality paper is often produced during start up of the paper machine, when a breakdown occurs, or when there is difficulty in transferring the web between sections. Wet paper produced during these periods is referred to as wet broke and dry paper as dry broke. Both are usually re-pulped and stored for re-use or immediately blended back into the stock system as part of the furnish. There is also a continuous production of broke due to the need to trim a few centimetres off each side of the sheet at the couch roll and again at the dry end where the final sheet width is determined. The total broke production is typically 10 to 20% of total machine production.

9.2 Twin Wire Paper Machines

Since their introduction the 1950s, the use of twin wire formers in place of the traditional Fourdrinier has grown to the point that most new paper machines for lightweight grades such as newsprint and tissue have twin wires. Many older newsprint machines in Canada have been converted to twin wire operation in recent years. There are about 30 twin wire machines operating in Canada at the time of writing, made by a variety of manufacturers.

The Canadian designed Papriformer shown in Figure 29 is a typical example. The stock is directed through a nozzle the full width of the machine (up to about 10 m) vertically upwards between two Fourdrinier type wires. Initial dewatering and forming is accomplished by centrifugal action and pressure between the two wires as they pass over the two principal rolls, the breast roll and the couch roll. Most of the white water is thrown out by centrifugal action and is collected for reuse in stock dilution. A very wide variety of configurations are used with twin wire machines, and the stock may be directed in almost any direction initially, including vertically downwards.

After forming the sheet passes on to the press and dryer sections similar to those already described.

9.3 Cylinder Machines

Cylinder machines are used primarily for the production of heavy grades of paper or board, and may use one or multiple cylinders to form the web, depending on the product.

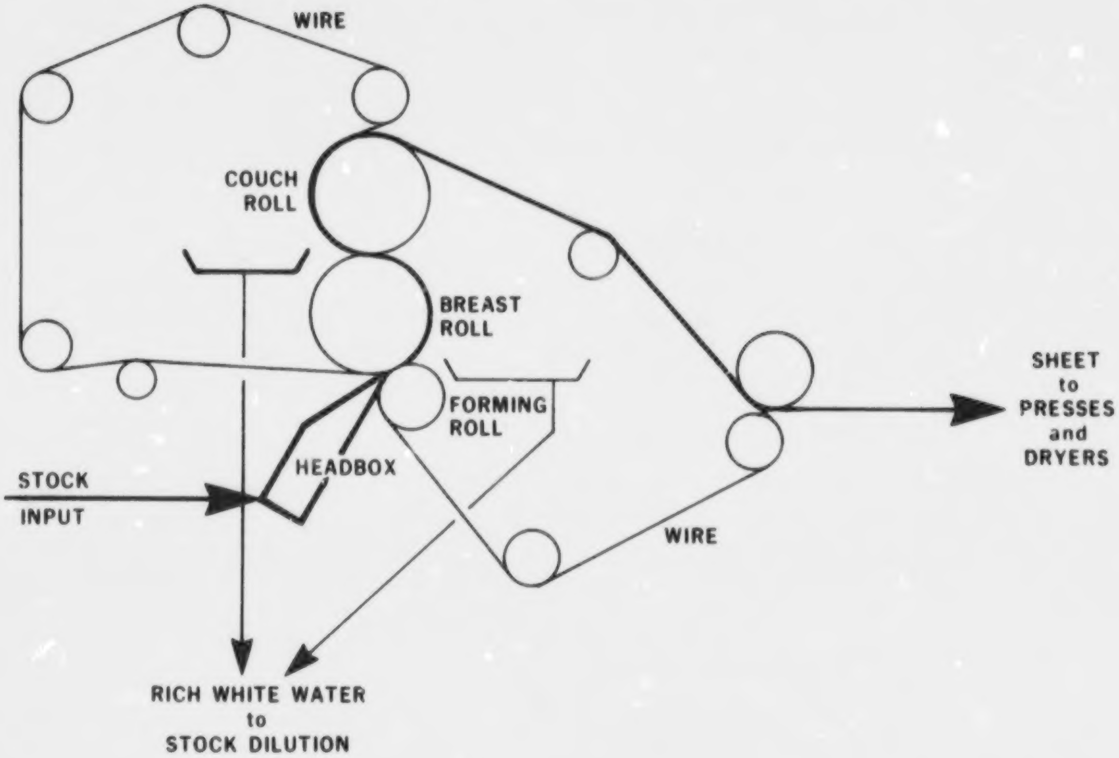
WIRE
COUCH ROLL
BREAST ROLL
FORMING ROLL
HEADBOX
STOCK INPUT
WIRE
SHEET to PRESSES and DRYERS
RICH WHITE WATER to STOCK DILUTION

FIGURE 29 TWIN WIRE FORMER (Papriformer)

In single cylinder machines the sheet is formed by depositing the thin stock on a cylinder covered with a fine mesh so that the water drains off back to the stock system and the web is carried on a supporting felt to the press and dryer sections as in the Fourdrinier machine.

In multi-cylinder machines, sheets are formed on several cylinders in line and laid one on top of the other to produce a very heavy board, which is then dried as described previously. Usually the outer plys are of a relatively fine stock for appearance or, in some cases, suitable for printing on. These machines operate at very slow speeds compared with the Fourdriniers or twin wire types, 40 m/min being typical.

9.4 Pulp Drying

Traditionally, pulp was dried for market on machines very similar to the paper machine shown in Figure 28. In the 1960s the air-flotation dryer, commonly known as a "FLAKT" dryer, after the name of a principal manufacturer, became popular. This replaces the multiple steam-heated drying cylinders with a series of tables where the pulp sheet floats on jets of hot air until dry.

In both the above types of dryer, the pulp produced is a thick, continuous sheet, similar to very heavy paper, and is cut into sheets and baled for storage or shipping.

Another development in pulp drying is the flash dryer which replaces the whole conventional pulp drying department. The pulp is pressed to about 40% consistency without first being formed into a sheet and then dried as a suspension of fibres in heated air. The dried fibres are separated from the hot air in a cyclone and pressed into bales.

9.5 Vacuum Pumps

Fourdrinier and twin wire paper machines make extensive use of vacuum for sheet and felt dewatering. The most common means of applying this vacuum is the liquid ring vacuum pump, often called the Nash pump, after the name of the largest manufacturer. These pumps have a circular rotor mounted eccentrically in a circular housing and rely on water to seal the rotor vanes to the casing. This type of pump has a number of advantages over other vacuum pumps, principally the ability to pump air mixed with water and some fibre. However, the seal water flow is large, typically about 10 m^3/tonne paper produced. This flow is usually only slightly contaminated with fibre and can, in many cases, be discharged directly to the receiving water. It is possible for several hundred kg/d fibre to be discharged via this route in some cases, although various mitigating measures such as in-line separators can be installed to avoid this problem. The high flow can raise effluent treatment costs substantially, but the cost of segregating this flow in older mills can be prohibitive.

The seal water for liquid ring vacuum pumps must not be confused with the pump shaft seal or gland water which is used in most process pumps. This latter flow is typically several litres per minute at each pump, a minor flow compared with the vacuum pump seal water.

9.6 Effluents

Stock generally arrives in the paper machine area at a consistency of between 3% and 12%. The final product is about 90% dry, so that from about 7 to 30 tonnes of water must be discharged per tonne paper produced. In addition, up to about 15 tonnes water per tonne paper are added by the paper machine showers and pump and agitator seal water, which must also be discharged at some point.

About 1.5 tonnes of water per tonne of paper is evaporated, and a large proportion of the remaining water is used for stock dilution prior to the paper machine area or for washing in bleach plants. However, there is usually excess white water to be discharged to sewer, which inevitably contains suspended solids in the form of fine fibres and, in some cases, fillers. If the mill has a modern disc saveall properly integrated with the white water system, only clear dropleg filtrate will be discharged to sewer, except during shutdowns or grade changes. For most mills the suspended solids concentration of this stream would be under 150 mg/L, and the mass flow of suspended solids would be under 3 kg/t paper, perhaps almost zero. If the mill produces filled or coated paper, these discharges could be much higher. Frequent grade changes also tend to cause relatively high suspended solids discharges with the white water. Unfortunately it is a characteristic of the paper market that the filled papers are produced in relatively small batches, requiring frequent grade changes.

Paper machine effluents can often be reduced substantially by improvements in recycle systems, and the current average discharge prior to any external effluent treatment is probably less than half the level of 1970. In some paper machines there is room for much more progress, whereas others already have very low discharges.

In some mills, a modern disc saveall cannot be justified by fibre savings, in which case the white water flow discharged will be similar but the consistency will be higher, causing a discharge of up to 30 kg fibre per tonne paper. In some cases, a saveall is installed primarily to improve effluent quality.

All paper machines have an associated stock preparation area which generates further effluents as described in Sections 6 and 8.

The sources of BOD of paper mill effluents are dissolved wood organics and coating material. The quantities of dissolved wood organics have been discussed in Section 5. Generally none of these reach the paper machine in the case of bleached chemical pulps, but much of the organic loss appears in the paper machine sewer for other pulps.

Coating and filler materials include starches, latex and other organics. Some leak to sewer and about 20% of the total used in the mill is introduced to the white water by way of the broke system. Most of this is discharged to the sewer. The quantities vary widely, but 10 kg BOD/t paper is not unusual.

The toxicity of chemical additives deserves mention. In general, the chemical concentration of additives used in a stock system is sufficiently low as to have no toxic effect. However, at high concentration, some of them may be quite toxic. The use of some highly toxic chemicals such as mercury compounds to control bacterial growth in the paper machine white water system has been discontinued in Canada.

9.7 Atmospheric Emissions

There are no environmentally significant atmospheric emissions for this department. By far the most noticable emission for the paper machine department is the vent from the dryer. This consists of water vapour and air. While normally environmentally insignificant, it is often misunderstood by the public due to its visibility.

9.8 Solid Wastes

Unless the cleaner rejects are dewatered and have to be disposed of, no solid wastes are produced in the paper machine department.

10 FINISHING AND CONVERTING

Finishing operations refer to those performed in the finishing room which are needed to prepare the paper for shipment. Finishing operations include:

- supercalendering in some cases to improve surface finish;
- secondary slitting and rewinding to produce rolls sized to the customer's requirements;
- cutting of the paper into sheets if the end product must be in sheet form rather than roll form;
- off-machine coating;
- wrapping.

Most of these operations produce little liquid waste except in the case of coating operations. It is sometimes necessary to sewer excess coatings and those of poor quality, and to flush out the system periodically.

Finishing operations can generate up to about 10% of total production as dry broke which is repulped and recycled at the stock preparation department.

11 CHEMICAL RECOVERY

The spent pulping liquor removed from the pulp in the washing stages contains virtually all the original cooking chemicals and organic material removed from the wood.

The quantity of total dissolved material depends principally on the pulping yield and is typically 1500 to 1900 kg/t for the kraft pulp and can vary from 500 to 2500 kg/t for sulphite and semi-chemical pulping. Chemical recovery is economically essential for a kraft process, but is primarily an environmental protection measure in most sulphite mills.

All kraft mills in Canada have chemical recovery operations, and a few sulphite mills do as well.

11.1 Kraft Chemical Recovery

11.1.1 Process Description. Figure 12 illustrated the fundamental kraft recovery process cycle in which the cooking chemicals are regenerated and the organic residues burned to produce energy for process and power. A brief summary of the process operations is given below:

- The weak black liquor removed from the pulp by the brown stock washers is concentrated in a set of multiple effect evaporators to about 50% solids. Natural convection circulation evaporators are normally used in Canada.
- This liquor is further concentrated to about 65% solids concentration either by direct contact with recovery furnace flue gas or indirectly in a forced circulation steam-heated evaporator, generally known as a concentrator.
- The strong black liquor is then burned in a recovery furnace. The organic matter burns, providing heat for steam generation, while the sodium sulphur salts accumulate in the hearth of the furnace as a molten smelt. At the high temperatures and controlled conditions employed, the Na_2SO_4 added to the black liquor as make-up for sodium and sulphur losses is reduced to Na_2S as follows:

$$Na_2SO_4 + 2C \xrightarrow[840°C]{} Na_2S + 2CO_2$$

- The molten smelt composed mainly of Na_2S, Na_2CO_3 and some unconverted Na_2SO_4 flows by gravity from the furnace and is mixed with weak wash, the filtrate from lime washing, in the dissolving tanks. The greenish colour of the molten salts is imparted to the water mixture and thus it is referred to as green liquor.

- The green liquor is pumped to a green liquor clarifier where carbonaceous ash residues, and other impurities are removed by sedimentation. The settled residue, known as green liquor dregs, or simply dregs, is washed to remove soluble sodium salts. The dissolved salts are returned to the system while the dregs are either hauled away for landfill or discharged to the sewer. Typically about 0.5 kg dregs are generated per tonne pulp.
- The clarified green liquor is then pumped to the causticising department where calcium hydroxide is added in the slaker to convert the sodium carbonate to sodium hydroxide according to the reaction below:

  $$Ca(OH)_2 + Na_2CO_3 \longrightarrow 2NaOH + CaCO_3$$

  The reaction, which is rather slow, begins in the slaker and is completed in the causticisers, which are agitated retention tanks immediately downstream of the slaker. The calcium carbonate formed from the reaction is quite insoluble and is settled out of solution in the white liquor clarifier. The clarified solution withdrawn contains the two major active cooking chemicals, Na_2S and NaOH. This liquor is called white liquor and is ready for re-use in the digester.
- The calcium carbonate removed from the white liquor clarifier is pumped to a mud washer followed by a mud filter where it is thickened and washed to recover entrained sodium salts. The thickened $CaCO_3$ is then calcined in a direct fired lime kiln, which converts it to calcium oxide as follows.

  $$CaCO_3 + HEAT \longrightarrow CaO + CO_2$$
- The CaO produced is recovered and used in the slaker.

A general flowsheet of a typical older Canadian kraft recovery system is shown in Figure 30, including the principal emission points. The typical quantities in the recovery process are shown in Table 13.

The only solid wastes are the slaker grits which are non-reactive lime and inert mineral matter and the green liquor dregs consisting of carbon, ash and some sodium salts.

The principal organic discharge is the evaporator condensate, although much of the total flow would be recycled to the pulp washers.

The total flow of organic material from the pulp washers through to the recovery furnace should be noted, since it is equivalent to about 300 kg BOD per tonne pulp. In some internal recycle streams, the flow of organics can be up to ten times

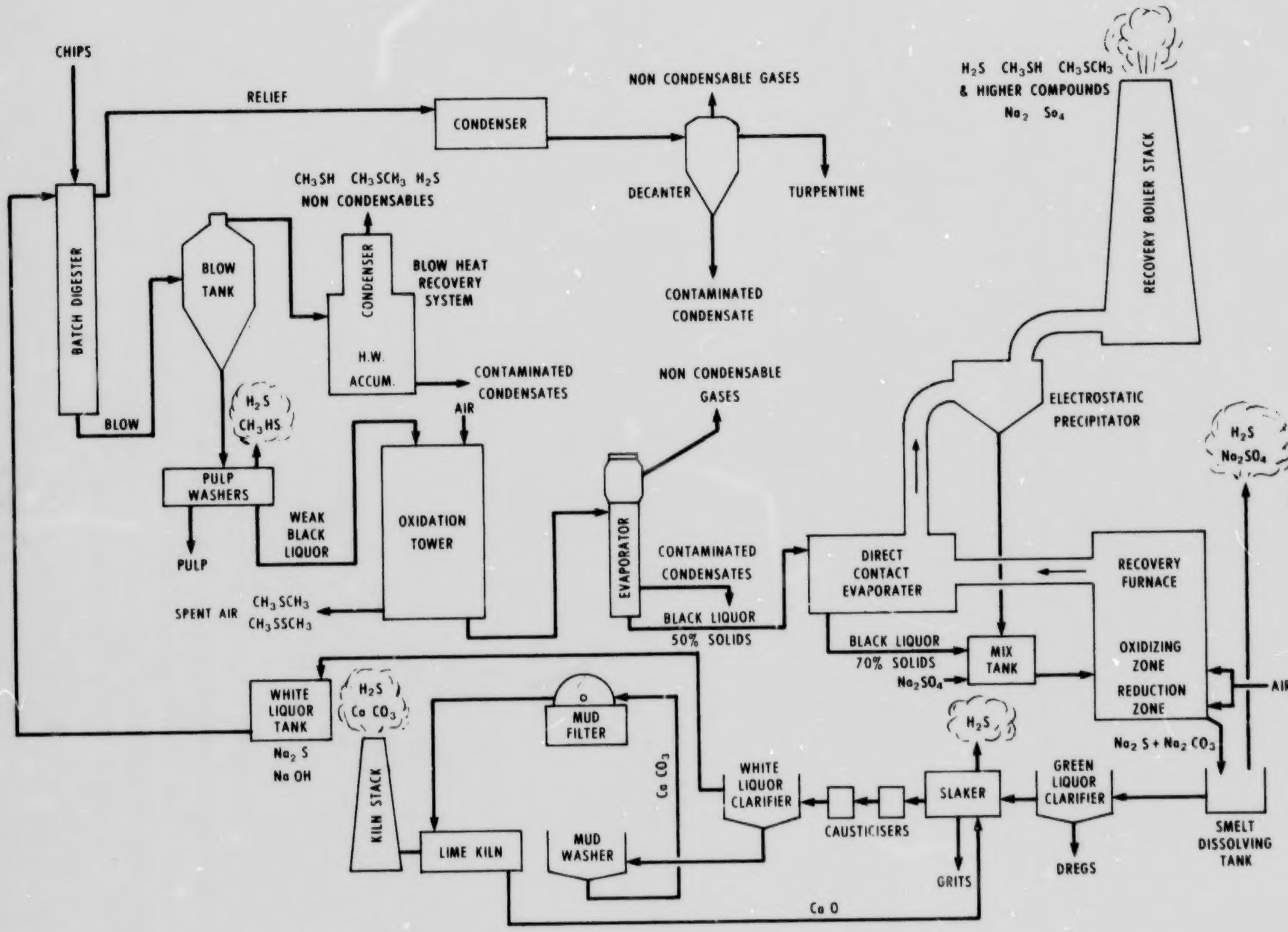
CHIPS
BATCH DIGESTER
RELIEF
BLOW
CONDENSER
NON CONDENSABLE GASES
DECANTER
TURPENTINE
CONTAMINATED CONDENSATE
BLOW TANK
CH_3SH CH_3SCH_3 H_2S
NON CONDENSABLES
CONDENSER
BLOW HEAT RECOVERY SYSTEM
H.W. ACCUM.
CONTAMINATED CONDENSATES
H_2S
CH_3HS
PULP WASHERS
PULP
WEAK BLACK LIQUOR
AIR
OXIDATION TOWER
SPENT AIR
CH_3SCH_3
CH_3SSCH_3
NON CONDENSABLE GASES
EVAPORATOR
CONTAMINATED CONDENSATES
BLACK LIQUOR
50% SOLIDS
H_2S CH_3SH CH_3SCH_3
& HIGHER COMPOUNDS
Na_2 So_4
RECOVERY BOILER STACK
ELECTROSTATIC PRECIPITATOR
DIRECT CONTACT EVAPORATER
BLACK LIQUOR
70% SOLIDS
Na_2SO_4
MIX TANK
RECOVERY FURNACE
OXIDIZING ZONE
REDUCTION ZONE
AIR
H_2S
Na_2SO_4
$Na_2S + Na_2CO_3$
SMELT DISSOLVING TANK
GREEN LIQUOR CLARIFIER
DREGS
H_2S
SLAKER
GRITS
CAUSTICISERS
WHITE LIQUOR CLARIFIER
$Ca\ CO_3$
MUD FILTER
MUD WASHER
LIME KILN
KILN STACK
H_2S
$Ca\ CO_3$
WHITE LIQUOR TANK
Na_2S
$Na\ OH$
$Ca\ O$

FIGURE 30 KRAFT PULPING PROCESS SHOWING PRINCIPAL EMISSIONS

TABLE 13 TYPICAL MASS AND ENERGY FLOWS FOR A 750 ADtpd BLEACHED KRAFT PULP MILL

	Steam Flow (t/h)	Water Flow (L/min)	Dry Solids Flow (kg/h)	BOD Flow (kg/h)
Wood into digester	-	1100	58500	-
White liquor into digester (Na_2O)	-	2450	9800	1960
Pulp wash water flow	-	5150	0	0
Steam to digester	57	-	-	-
Weak black liquor to evaporators	-	4950	58250	8700
Steam to evaporators	71	-	-	-
Evaporater condensate	-	4400	-	400
Strong black liquor to furnace	-	550	59000	8300
Steam Produced	138	-	-	-
Saltcake make-up	-	0	700	0
Green liquor dregs	-	7	20	3
Lime feed to slaker	-	0	7000	0
Slaker grits	-	3	50	0
Lime mud flow to thickener	-	280	11200	200

Note: Inorganic chemicals such as white liquor exert a BOD due to chemical oxidation of sodium sulphide under the conditions of a BOD test.

greater so it is clear that even a very small percentage loss of this flow, which passes through much complex equipment, would represent a substantial BOD load on the waste treatment plant or receiving water.

11.1.2 **Evaporators.** The weak black liquor is received at the recovery department at a concentration of about 14 to 18% solids. This concentration must be raised substantially by evaporation before the liquor can be fed to the recovery furnace. Specially designed vertical shell and tube heat exchangers called evaporators are most commonly used in Canada for the evaporation process. The weak liquor is boiled in the tubes by steam fed to the shell. A large vapour head is installed at the upper end so that the vapour can separate from the liquor with a minimum of carryover. There are normally from five to seven stages, known as effects, in series and the vapour from one is used as the steam supply for the next. The bodies and heat exchange surfaces are designed so that the pressure drops successively from about 200 kPa, a typical feed pressure for the live steam, to about 90 kPa vacuum. The black liquor generally flows countercurrent to the steam, but a variety of sequences are used.

The vapour evaporated in any one effect is condensed in the next, and the vapour from the final effect is condensed in either a large heat exchanger known as a surface condenser or by direct contact with water in a barometric condenser. A surface condenser requires a small vacuum system to remove non-condensable gases from the system. These gases consist of methanol, terpenes and other organics, air and a group of malodourous sulphur compounds known generally as total reduced sulphur (TRS).

Volatile organic compounds, principally methanol, condense in the shells of the surface condenser and the evaporators and, if sewered, constitute a major BOD source. The amount of BOD varies and is typically in the range 8 to 15 kg/tonne. There is a discrete condensate stream from each body, but the BOD distribution is very uneven, and it is normal practice in the more modern mills to segregate the condensate streams to facilitate reuse. All the condensate is hot, of course, and the cleaner streams are suitable for use in the recausticising and pulp washing departments.

The condensates are also contaminated with black liquor which is carried over in the vapour heads of the evaporators. The designer's objective is to minimise this carryover, and in well-designed, adequately sized units it is usually negligible. However, multiple-effect evaporators are not easy to operate, and liquor carryover is a frequent problem and can contribute several kg BOD/tonne pulp to the effluent.

A typical evaporator and soap recovery flowsheet is shown in Figure 31. The off-gases from the evaporators and any condensate stripping operations constitute a major TRS emission. Emission rates and control practices are discussed in Section 14.

11.1.3 Soap Recovery. Soap skimming has long been a part of the kraft process but in recent years it has become more important. The major reason is that resin acids contained in the soaps are one of the major toxic components in pulping effluents and have an adverse effect on biological waste treatment systems. Soap skimmings consist largely of resin acids and fatty acids present in the original wood which on pulping become saponified in the alkaline liquor, forming their sodium salts. In the dilute spent cooking liquor these salts remain soluble, but during evaporation their solubility decreases to the point where they begin to "salt out". This usually occurs at a black liquor solids concentration of 25 to 35%. This material is termed soap and is usually removed by a rotating paddle at the surface of the liquor in a skimming tank. In Figure 31 the liquor

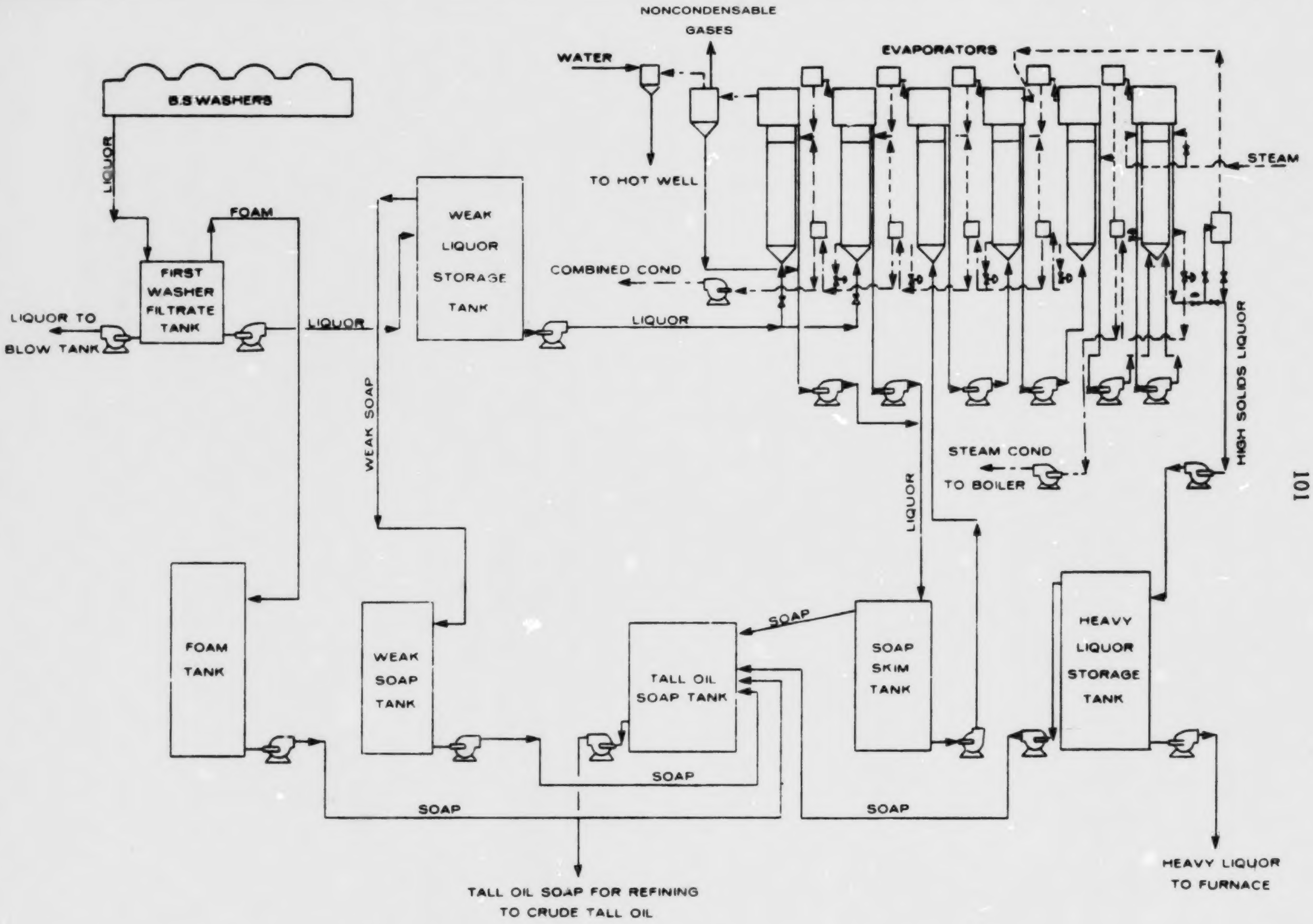
NONCONDENSABLE GASES
WATER
EVAPORATORS
B.S WASHERS
LIQUOR
FOAM
TO HOT WELL
STEAM
WEAK LIQUOR STORAGE TANK
FIRST WASHER FILTRATE TANK
COMBINED COND
LIQUOR TO BLOW TANK
LIQUOR
LIQUOR
HIGH SOLIDS LIQUOR
WEAK SOAP
STEAM COND
TO BOILER
LIQUOR
FOAM TANK
WEAK SOAP TANK
SOAP
TALL OIL SOAP TANK
SOAP SKIM TANK
HEAVY LIQUOR STORAGE TANK
SOAP
SOAP
SOAP
TALL OIL SOAP FOR REFINING TO CRUDE TALL OIL
HEAVY LIQUOR TO FURNACE

FIGURE 31 BLACK LIQUOR EVAPORATION AND SOAP RECOVERY FLOWSHEET

leaving the fifth and sixth effect evaporators is sent to the skim tank. In some plants the skim tank is located between the fourth and fifth effects.

An adequate retention time in the tank (1.5 to 2.5 hours) permits the soap to float to the top. The skimmed soap is usually collected in a soap tank where upon it is sold or, if the mill has a tall oil plant, it will be sent to it for further processing. Alternatively, it is burned in the recovery furnace, effectively destroying it and recovering the heat and chemical value. Other minor quantities of soap are collected from the weak black liquor storage tank as well as from the strong black liquor storage tank. Because soap recovery is not highly efficient at weak liquor concentrations, some resin acids remain in the black liquor.

If no soap skimming equipment is installed, layers of soap usually tend to form on top of the strong black liquor storage tanks where some of this overflows to sewer. Some mills with lower soap content liquor can effectively control soap losses simply by intermittently pumping off this layer and incinerating it.

11.1.4 Black Liquor Oxidation. When sodium sulphide in black liquor comes into contact with the carbon dioxide from the recovery furnace flue gases in the direct contact evaporator, quantities of hydrogen sulphide may be generated, stripped from the liquor and emitted into the atmosphere. This generation of H_2S can be largely eliminated by oxidizing the sodium sulphide with air (or in rare cases, oxygen) to sodium thiosulphate. This oxidation may be performed before or after the multiple effect evaporators or at both locations. A number of mills in Canada have air oxidation systems.

The oxidation can be carried out in packed towers, plate towers or in tanks fitted with sparging nozzles. Foaming problems occur frequently, particularly in liquor from resinous woods, and are usually more severe in weak black liquor oxidation systems. Systems have been designed with foam tanks and foam breaking equipment to minimize the problem.

Weak black liquor oxidation reduces evaporator corrosion, TRS emissions, and evaporator foaming, and results in less evaporator carryover. This can be an important factor in reducing the toxicity to fish of the evaporator condensate. Because of the retention time through the evaporators and in storage tanks, some reversion of the oxidized sulphur compounds may occur. For this reason strong black liquor oxidation is frequently required to achieve a satisfactory level of sodium sulphide residual in the black liquor entering the direct contact evaporator. Sodium sulphide residuals of 0.1 g/L or lower have been shown to largely eliminate the generation of H_2S in the direct contact evaporator. Sodium sulphide residuals of 0.2 g/L to 0.4 g/L have been shown to be effective if the black liquor pH is over 12.

The quantity of TRS emitted by black liquor oxidation systems depends on the processing sequence, but under a combination of adverse factors it may be as high as 0.2 kg/t pulp. Incineration by using the off gases as combustion air is sometimes practiced.

11.1.5 Direct Contact Evaporators. Most recovery furnace systems installed before 1973 use a "direct contact evaporator" to concentrate the black liquor from the multiple effect evaporators from about 50% concentration to about 65%. The operating principle is the direct contact of hot recovery furnace flue gases with the black liquor, either in a cyclone or in a cascade evaporator in which a slowly rotating steel cage is partially immersed in a bath of liquor, and partly in the hot gas stream.

The vapours evaporated are discharged to the atmosphere along with the combustion gases. In some cases, the discharge consists almost entirely of water vapour, carbon dioxide and nitrogen. However if the black liquor is not well oxidised, up to several hundred parts per million (ppm) hydrogen sulphide and small quantities of other reduced sulphur gases will be generated in the direct contact evaporator by reaction between the carbon dioxide in the flue gas and sodium sulphide in the unoxidized black liquor. These represent one of the major TRS emissions in some mills.

If the recovery furnace is a low-odour type as described below, the oxidation of black liquor is irrelevant to boiler TRS emission.

11.1.6 Recovery Furnaces. The recovery furnace, frequently known also as the recovery boiler, is the heart of the recovery system. The concentrated black liquor at 60 to 70% solids is usually mixed with the make-up chemicals such as sodium sulphate and, occasionally, ClO_2 generator spent acid, and sprayed into the recovery furnace for burning. Figure 32 is a sketch of the furnace showing the three major operating zones. Black liquor droplets are dried as they drop through the drying and reducing zones to the smelt bed. Primary air flow must be restricted to a level to provide reducing atmosphere in the lower level of the furnace. The primary air flow is the means of controlling a proper smelt bed temperature. If the bed temperature is too low, insufficient sodium compounds will be volatilized into the reducing zone to combine with the sulphur compounds present and higher sulphurous compound emissions from the furnace will result. If the bed temperature is too high, excessive amounts of sodium compounds will be carried out of the furnace as particulate matter. As the gases from combustion pass up

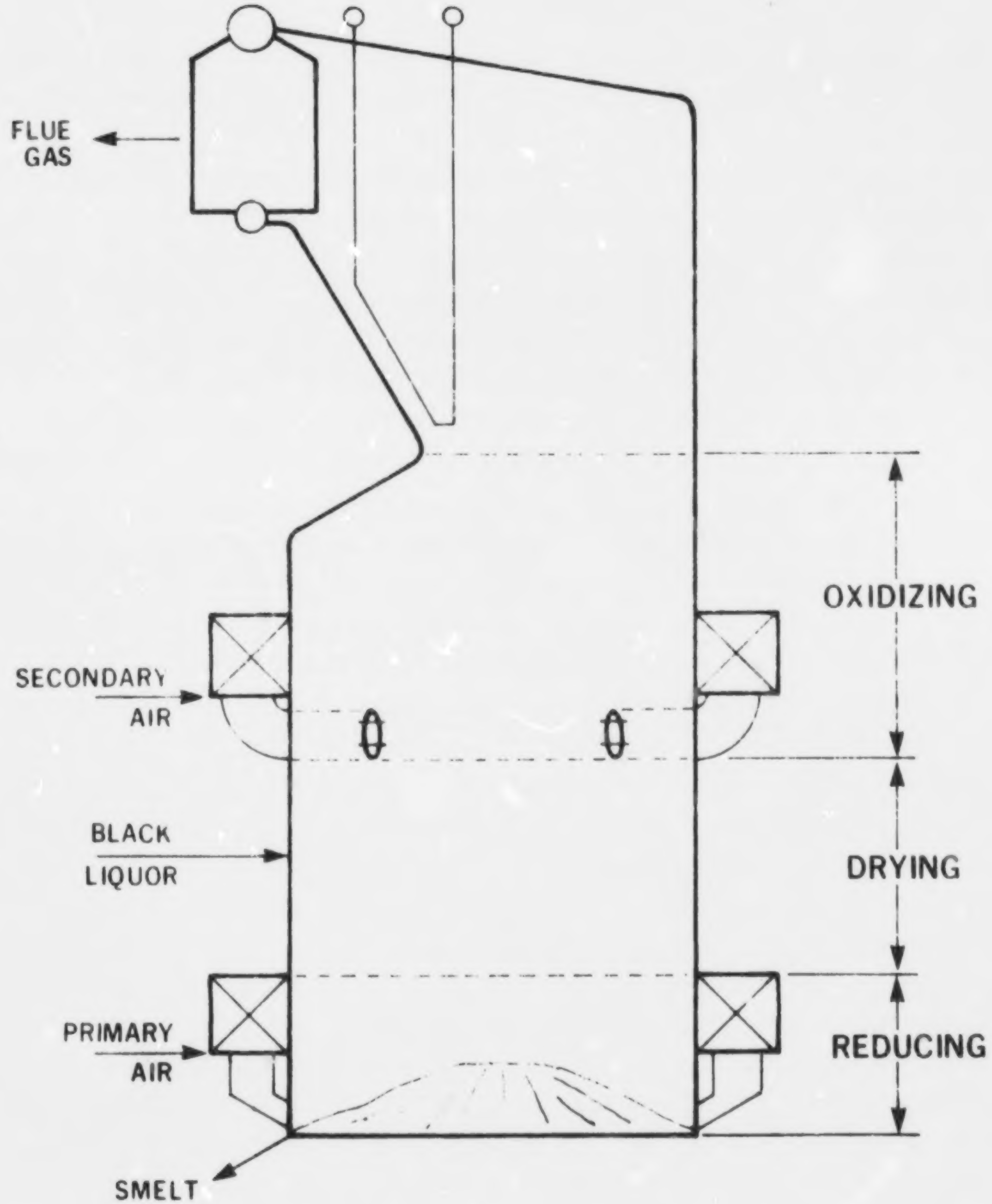
FLUE GAS
OXIDIZING
SECONDARY AIR
BLACK LIQUOR
DRYING
PRIMARY AIR
REDUCING
SMELT

FIGURE 32 CHEMICAL RECOVERY UNIT FURNACE ZONES

through the oxidizing zone, the organics are oxidised, principally to CO_2 and H_2O, completing the process. Many furnaces have an additional feed of air introduction known as tertiary air.

The operation and design of the furnace are very important in the regulation of emissions. With proper turbulence, bed temperature, and air distribution, essentially all the sulphur will combine with sodium and remain with the smelt, mostly as sodium sulphide. Maintaining an oxygen concentration in the flue gas of at least 2% at the furnace exit is usually essential to maintain the TRS emissions at a minimum. If the excess oxygen is too high the formation of sulphur trioxide may give problems by causing particulate material to stick to the furnace tubes. Many older furnaces are undersized by today's standards and are incapable of maintaining any oxygen in the flue gas.

A number of the operating variables, including such apparently minor items as the size of the black liquor droplets sprayed into the furnace, are important in the control of the emissions. Large variations in the black liquor feed to the furnace will result in an upset in the mixing and velocity of gases so that excessive amounts of sulphur compounds will escape with the flue gas. Note that generation of TRS in the direct contact evaporator as discussed above is largely independent of recovery furnace operations.

The recovery furnace is a major source of particulate emissions from the kraft mill. The particulate material is largely sodium sulphate and sodium carbonate, but in coastal areas where the wood supply is transported and stored in salt water, it may contain significant amounts of sodium chloride. The recovery of 85 to 95% of particulate emissions through the use of electrostatic precipitators or scrubbers is normally practiced for economic reasons. This level of efficiency combined with the direct contact evaporator results in particulate emissions of 5 to 15 kg/t pulp. Newer precipitator installations are commonly designed for particulate removal efficiencies in excess of 99% due to stringent environmental regulations and because direct contact evaporators are no longer being installed.

The term low-odour recovery furnace is used for boilers without direct contact evaporators, as shown in Figure 33. These units require larger, more efficient electrostatic precipitators to achieve equal control of emissions. Electrostatic precipitators, in practice, commonly will not meet design emission levels. In use, the efficiency tends to fall off rapidly and maintenance requirements are heavy. However, particulate emissions of less that 1.5 kg/t have been reported.

TRS stack emissions from a low-odour recovery furnace have been reported to vary from a low of 1 ppm to several hundred parts per million under overloaded or upset

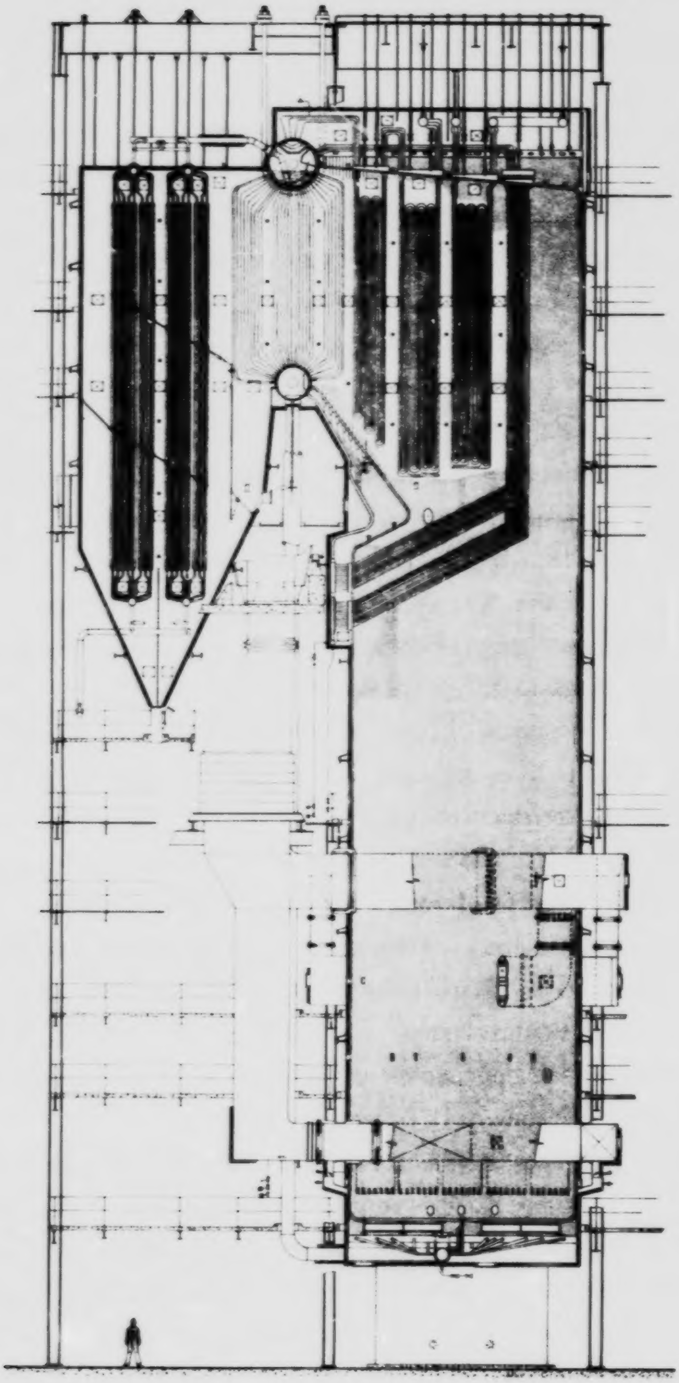

FIGURE 33 LOW-ODOUR RECOVERY FURNACE
(Combustion Engineering Canada)

conditions. The TRS emissions from a conventional recovery furnace under good operating conditions with a direct contact evaporator and well-oxidized black liquor have been reported as low as 2 to 3 ppm. However, significant sampling and testing errors may be introduced when measuring TRS at these low concentrations and much of the older data in the literature is seriously understated.

Modern recovery furnaces, whether direct contact evaporators using well-oxidized black liquor or low-odour units, achieve TRS emissions of under 20 parts per million when good operating procedures are practiced. The TRS emissions from poorly operated or overloaded recovery furnaces can exceed 1 000 ppm. Units installed more than 10 to 15 years ago may have difficulty in achieving emissions of less than 100 ppm because of design and instrumentation limitations, even if they have good black liquor oxidation systems. Regulations notwithstanding, few recovery furnaces with TRS emissions of 100 ppm are a source of odour at ground level.

Sulphur dioxide emissions may vary from a few parts per million to several hundred parts per million, depending on furnace operating conditions and the type of furnace. The direct contact evaporator of a traditional recovery furnace scrubs out most of the sulphur dioxide from the flue gas. For this reason a low-odour furnace will normally have higher sulphur dioxide emissions than a traditional furnace. These emissions are not normally large enough to be considered environmentally significant and correspond to the combustion of very low sulphur oil.

Scrubbers are sometimes used to control particulate emissions, either separately or in series with electrostatic precipitators, and can remove more than 90% of the particulate material. They are generally more reliable than electrostatic precipitators but generate a highly visible wet plume. In some areas under unfavourable weather conditions the wet plumes from units equipped with scrubbers may result in severe visibility problems, or create adverse public reaction due to misinterpretation of the plume by laymen.

Commercial operations have demonstrated the capability of a system using an alkaline activated carbon scrubbing medium, developed by the Pulp and Paper Research Institute of Canada, to control both particulate and TRS emissions from many existing recovery furnaces. Several installations using this system are in operation in the U.S.A. and Canada.

11.1.7 Smelt Dissolving Tanks. The molten smelt which flows from the smelt bed in a recovery furnace is composed mainly of sodium carbonate and sodium sulphide. This smelt drops through steam shatter sprays into a dissolving tank. Large amounts of steam are released when the smelt contacts the water and some particulate material is carried out of the stack with the steam. Packed scrubbers or mesh pads with showers may be used to control these particulates. Care must be taken in the design of control devices because of the danger of plugging. Particulate emissions can be controlled to levels of 0.1 kg/t pulp.

TRS emissions, which are usually minor, may originate from the smelt and weak wash in the smelt tank itself or from the shower water used in the control equipment. Emission levels of approximately 0.01 kg/t pulp have been reported. Control of TRS emissions from this source is not normally practiced.

11.1.8 **Slakers and Causticisers.** Green liquor from the dissolving tank is causticized by mixing lime and water in a slaker. The reaction in the slaker takes place at around 100°C. This reaction produces some steam which carries both particulate matter and TRS gases out of the vent. The emissions are not well documented, but the particulate emissions are small and the TRS emissions negligible.

11.1.9 **White Liquor Production.** The mixture of calcium carbonate, sodium sulphide, sodium hydroxide and water produced by the causticiser is routed to the white liquor clarifier where the calcium carbonate settles out. The clarifier product is white liquor, which is the principal chemical ingredient in the cooking liquor required in kraft pulping as described in Section 5.3.

The settled mud is washed by dilution; rethickened in another clarifier known as the lime mud washer; thickened to about 70% consistency in a vacuum filter; and re-calcined to quick lime, CaO, in the lime kiln.

A few mills use fluidised bed calciners instead of lime kilns.

11.1.10 **Lime Kilns.** The rotary lime kilns used in most kraft pulp mills are large brick-lined steel cylinders 2 to 3 m in diameter and 50 to 100 m long. They are inclined a few degrees from the horizontal and rotate slowly. The kiln is heated by a burner at the lower end and the washed, thickened lime mud is introduced at the upper end. The mud, together with make-up limestone, moves slowly down the kiln while the temperature is raised to above 825°C, the decomposition temperature of calcium carbonate. The high temperatures decompose the calcium carbonate to calcium oxide and carbon dioxide. The resultant quick lime is used in the causticising process. The gases passing through the kiln carry particulate calcium and sodium compounds and TRS to the discharge stack.

A small amount of sodium compounds in the mud is desirable to help prevent the lime from sticking to the sides of the kiln and to control the size of the lime balls formed in the kiln. Excessive amounts of sodium compounds in the mud cause the lime to be too sticky. Particulate matter is generated from the tumbling action of the material in the kiln and is carried along with the combustion gases. Some of the residual sodium compounds volatize at the high kiln temperatures and are subsequently discharged as a flume. Some of the sodium sulphide left in the lime mud after washing generates hydrogen sulphide in the presence of carbon dioxide in the flue gas and may be emitted from the kiln. Weak wash is commonly used as a source for lime mud filter shower water and lime kiln exit gas scrubber water and may be a major source of lime kiln TRS emissions.

The emissions from the kiln depend on the efficiency of the mud washing, the temperature at the cold end of the kiln, the nature of the lime mud, the nature of the scrubbing medium and other operating conditions.

Lime kiln particulate emissions are generally controlled with wet scrubbers or, occasionally, by electrostatic precipitators. Particulate emissions can be controlled to levels of less than 0.5 kg/ADt by either device.

TRS emissions may be controlled to some extent by the wet scrubbers, depending on the scrubbing medium. The use of sodium hydroxide in the scrubber significantly reduces TRS emissions. TRS levels of less than 0.003 kg/t pulp have been reported when NaOH is used.

Good operating practicies, including good lime mud washing and the use of non-contaminated scrubber shower water, should result in TRS emissions of 0.05 kg/t or less.

11.1.11 **Effluents.** Theoretically, the only effluents from the kraft recovery areas would be evaporator condensates, green liquor dregs, and slaker grits as discussed above. However, intermittent discharges due to spills of black liquor can reach 20 kg/BOD per tonne pulp. good design and operating practices will reduce these spills to a few kg/t, and a spill controlsystem can reduce them to neglegible levels.

11.1.12 **Atmospheric Emissions.** The sources of atmospheric emissions in kraft recovery have been discussed for each item of equipment as it was described above. Further emission data for complete kraft mills, including the recovery department, is included in Section 13.

Vents from black liquor storage tanks and chemical effluent drains can be classified as minor sources. Sources such as screen room ventilation, effluent treatment lagoons and ponds do not normally emit so much TRS as to require control. If lagoons have odourous emissions they can usually be controlled by appropriate in-plant measures, most commonly condensate stripping.

Materials handling can present minor particulate emission problems around kraft pulp mills. Lime and saltcake may present dust problems. Recently constructed plants have reduced the problem with enclosed handling and conveying equipment.

11.1.13 Solid Waste. The slaker grits are usually landfilled as an inert sludge at over 40% concentration. In mills where the green liquor dregs are washed on a vacuum filter, these are also landfilled, usually with the slaker grits.

11.2 Sulphite Process Recovery

More than a dozen types of chemical recovery systems are in operation for the sulphite process throughout the world, using widely differing processes. In Canada, the mills operating combustion units have different systems for recovering cooking chemicals. Two mills process spent liquor and sell the by-products. Generally only low-yield systems are considered suitable for recovery processes.

All the systems concentrate weak spent cooking liquor, called red liquor, from the washers in multiple-effect evaporators. Some systems further concentrate the liquor before incineration by using the heat in the recovery furnace flue gases, while others incinerate the liquor directly from the evaporators.

The following factors are pertinent to sulphite recovery in general:

- Sulphite recovery technology is still in state of flux but there seems to be less research than there was in the late 1960s and early 1970s. Several new systems have been proposed but few companies are willing to install an unproven system in the face of changing environmental requirements, an uncertain economic outlook and high capital costs.
- Most mills have widely differing requirements in relation to wood species, cooking liquor composition, recovery load, pulping yield, and possible integration alternatives.
- The dwindling supply of prime wood and rising wood costs appear to be further reasons for not investing in sulphite operations, which are limited to a few wood species.

- A possible economic alternative in the light of present conditions is for some low yield plants to convert to high yield sulphite. This gives a 20 to 50% reduction in BOD loading and minimizes the size of any future secondary waste treatment facilities. Such a move also reduces the heating value of the spent liquor, making economic justification for a future recovery system less likely.
- The many small Canadian sulphite operations present a rather difficult dilemma. They are too small to even consider a recovery system and yet are pressed by environmental authorities to reduce BOD discharges and the toxic nature of the spent liquors. Forcing the shut-down of such plants would be economically disastrous to many small communities.

11.2.1 **Concentration of Weak Liquor.** Weak red liquor from the washers, containing 9 to 15% solids, is concentrated in a multiple-effect evaporator similar to kraft recovery systems. The maximum concentration of weak red liquor is attained when the digesters are heated indirectly and vacuum washers are used. If red liquor from blow pit diffusion washing is used, the solids concentration would be under 7%. A vacuum washing system is usually necessary if chemical recovery is to be feasible; otherwise the steam requirement for liquor evaporation would be excessive. Multiple-effect evaporators of three to six effects, similar to kraft evaporators, may be used. The strong red liquor discharged from the evaporators may vary from 35% to 60% solids depending on the type of the combustion unit. Generally sulphite liquor is corrosive and causes excessive scaling and other operating problems in the evaporators, which give rise to high operating costs and relatively frequent BOD spills.

The only atmospheric emission of significance from the evaporators is sulphur dioxide which can amount to 50 kg/t pulp and is usually returned to the process. The condensate BOD is high, as discussed in Section 11.2.4.

11.2.2 **Liquor Combustion and Recovery Furnaces.** The spent liquor combustion units may differ extensively depending on the base chemical used in cooking and other process variables. When calcium is used, the calcium is converted to calcium sulphate and calcium carbonate and some of the sulphur is oxidized to sulphur dioxide. If ammonia is used, the base chemical decomposes and the sulphur is oxidized to sulphur dioxide. When magnesium is used, magnesium oxide dust, resulting from the decomposition of magnesium compounds, is collected after combustion and used to absorb the sulphur dioxide in a scrubbing system. When sodium is used, a smelt of molten sodium compounds results (similar to kraft liquor burning). Some of the sulphur may also be oxidized to sulphur dioxide.

Sulphur dioxide in the flue gas from any of the combustion operations is recovered for reuse by scrubbing with the base chemical slurry or solution. Cooking chemical losses are made up with sulphur dioxide, prepared by burning sulphur, and purchased base chemical.

Sodium liquors are burned in units similar to kraft recovery furnaces or in fluidized bed units. With a sodium based liquor, some sulphite processes convert the sodium to a form that is reusable in cooking acid by means of a complicated recovery cycle. When sodium based liquor is burned in a fluidized bed the sodium is converted to a mixture of sodium carbonate and sodium sulphate. This mixture may be used for kraft mill make-up chemical, in the unlikely event that sufficient local demand exists, but it is not suitable for reuse in sulphite cooking. Some of the sulphur is oxidized to sulphur dioxide.

For large production operations the use of magnesium base recovery has been successful. The basic process is illustrated in Figure 34. The weak liquor at about 12% concentration is recovered by counter-current washers, concentrated in multiple-effect and direct contact evaporators to 60% to 65% solids, and sprayed into a conventional recovery furnace. The combustion products are a carbon-free MgO ash and SO_2. The gases pass through a series of multiple cyclones where 85% of the ash is collected and flushed with water to a retention tank. The MgO slurry is then converted to $Mg(OH)_2$ in the slaking system and used for absorption of the SO_2. The heat value of the organic residues in the spent liquors is recovered as steam for power and process use. The overall chemical recovery of sulphur and $Mg(OH)_2$ is around 80%. An alternative magnesium recovery system employs a fluidized bed reactor in place of the furnace. This system permits the firing of solids at a concentration of 35 to 40% rather than the usual 60 to 65%, but with lower overall thermal efficiency.

Calcium based liquors may be burned in "add on" combustion units. These units have been used in regular power boilers. The calcium is converted to calcium sulphate and carbonate and is discarded. Most of the sulphur is oxidized to sulphur dioxide. The use of calcium as a base is being phased out for a number of reasons, including its low solubility. There are no mills burning calcium base liquor in Canada and most of those overseas have shut down due to high SO_2 emissions.

When ammonia based liquors are burned, there is no need to collect solids or smelt, and add-on combustion units are not necessary. The ammonia decomposes and the sulphur is oxidized to sulphur dioxide.

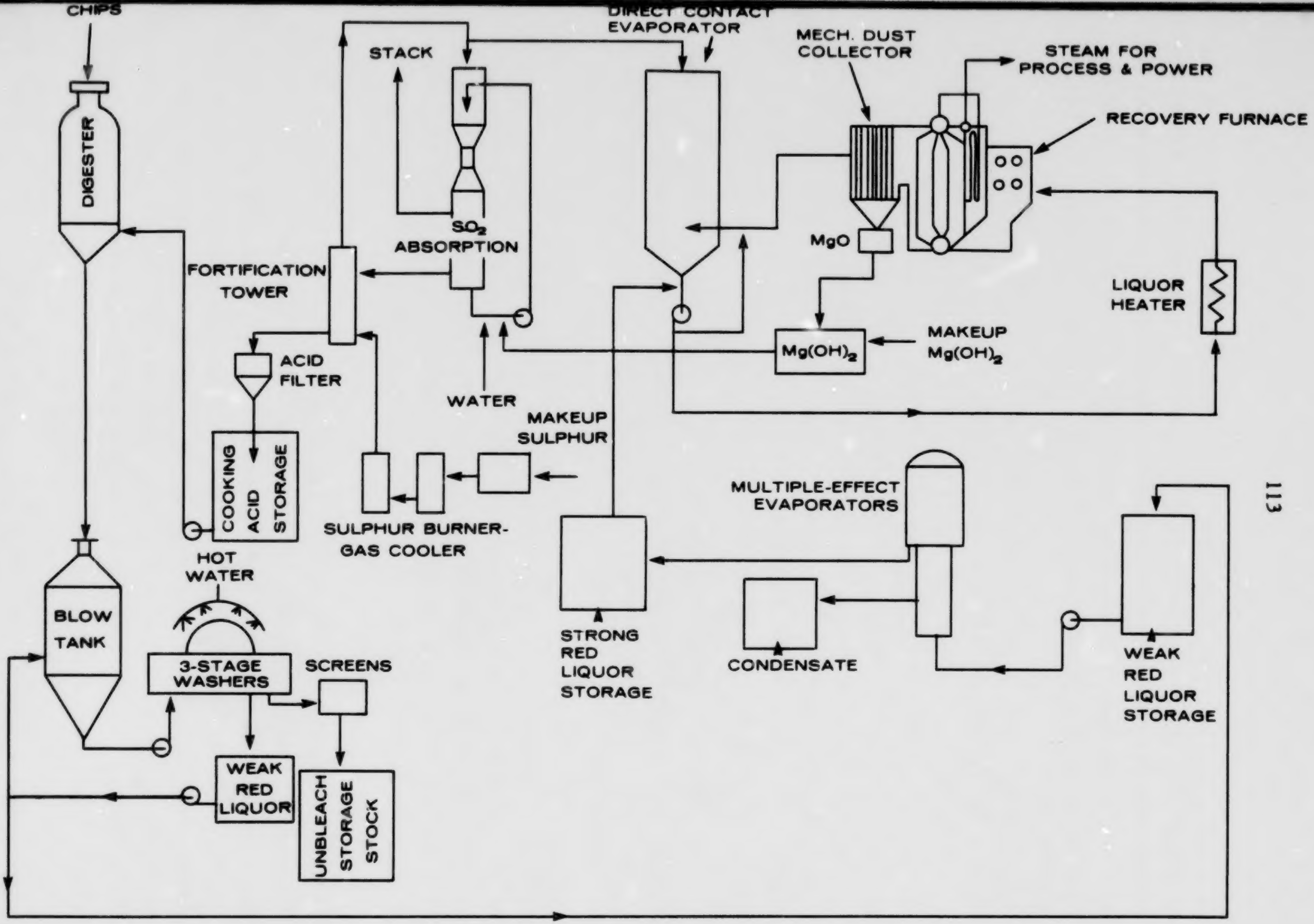
CHIPS
DIGESTER
STACK
SO$_2$
ABSORPTION
DIRECT CONTACT
EVAPORATOR
MECH. DUST
COLLECTOR
STEAM FOR
PROCESS & POWER
RECOVERY FURNACE
FORTIFICATION
TOWER
MgO
LIQUOR
HEATER
ACID
FILTER
WATER
Mg(OH)$_2$
MAKEUP
Mg(OH)$_2$
MAKEUP
SULPHUR
COOKING
ACID
STORAGE
SULPHUR BURNER-
GAS COOLER
MULTIPLE-EFFECT
EVAPORATORS
HOT
WATER
BLOW
TANK
3-STAGE
WASHERS
SCREENS
STRONG
RED
LIQUOR
STORAGE
CONDENSATE
WEAK
RED
LIQUOR
STORAGE
WEAK
RED
LIQUOR
UNBLEACH
STORAGE
STOCK

FIGURE 34 FLOW DIAGRAM OF MAGNESIUM BASE RECOVERY SYSTEM

The sulphur dioxide produced in any of these combustion processes (except calcium base) is scrubbed from the flue gases along with particulates with a solution of base chemical (slurry when magnesium is used). This scrubber solution becomes cooking acid after fortification with additional sulphur dioxide. The sulphur dioxide used for fortification may be obtained from the burning of sulphur or from purchased liquid sulphur dioxide.

The control of most particulate emissions in many of these combustion units is achieved in flue gas scrubbers that have the primary purpose of recovery of sulphur dioxide for cooking acid manufacture. Units burning ammonia base liquor require a control device for removal of very fine particulates after the scrubber. Scrubbing can reduce the particulate emissions to less than 2.4 kg/t.

As a theoretical upper limit, uncontrolled sulphur dioxide emissions could be as high as 350 kg/t before scrubbing. After scrubbing, this emission is reported to be less than 10 kg/t. In the sodium base processes using recovery boilers similar to kraft recovery furnaces, the emissions are similar to those from the kraft process.

11.2.3 Miscellaneous Emission Sources. Miscellaneous sources emit mainly sulphur dioxide. These sources include the stripping of contaminated condensates, liquor and acid storage tanks, and chmical sewers. Little data are available on the level of emissions or on control methods.

Materials handling can cause fugitive dust problems around sulphite pulp mills. Wood chips, sulphur, limestone and magnesium oxide are among the materials handled which can present particulate fall-out problems. However, these tend to be local problems and no data are available on their magnitude. The unloading and storage of chemicals such as ammonia, sulphur dioxide and chlorine will cause emissions if proper handling procedures and maintenance are not followed. Again, no emission data are available and any problems tend to be very localised.

11.2.4 Effluents. Sulphite chemical recovery operations generally have much higher BOD discharges than their kraft mill counterparts. The principle source of this BOD is the condensate from the evaporators which contains acetic acid and other organics which are volatile at the conditions in the evaporator. The total BOD in the condensates depends on pulping yield, weak liquor pH and wood species, and is typically in the range 50 to 120 kg/t pulp, which is an order of magnitude greater than that from kraft pulping. The boiling point of acetic acid is very close to that of water, so steam stripping is quite inefficient as a means of reducing this source of BOD.

Sulphite liquor tends to cause extensive evaporator scaling, requiring frequent washing and maintenance. These activities lead to more frequent spills of liquor to sewer than in kraft mills, even with the most stringent precautions, and can easily add 20 kg BOD/t pulp to the mill effluent load.

11.3 Semichemical Process Chemical Recovery

The semichemical pulping processes produce much less liquor than the lower-yield kraft or sulphite processes. True chemical recovery is not presently feasible, except for a semichemical pulp mill that uses sulphur-free pulping.

Some mills collect spent pulping liquor in a manner similar to a kraft mill, or use high-consistency presses to separate the liquor from the pulp, and then evaporate the liquor to about 25% consistency and incinerate it in a fluidised bed furnace. Heat recovery is inefficient with this type of system. The furnace product is a mixture of sodium carbonate and sodium sulphate, which cannot be economically converted to useful pulping chemicals. It can, however, be used in kraft mills if there is sufficient kraft capacity within a reasonable distance and the sodium to sulphur ratio is compatible with the kraft mill's chemical balance.

The atmospheric emissions can usually be readily controlled to low levels by scrubbing and the evaporator condensates represent a minor BOD discharge compared with sulphite mills.

12 STEAM AND POWER GENERATION

12.1 Introduction

The steam energy used in pulp and paper mills is derived from three principal sources:

- combustion of waste pulping liquors which are produced in chemical pulping processes,
- combustion of wood refuse or hog fuels consisting of wood waste and bark, and
- combustion of fossil fuels such as oil, gas and coal.

In addition, a small amount of steam is generated industry-wide using electricity where it is favored by inexpensive hydro-electricity. As well, some low grade steam is recovered from processes such as thermomechanical pulping where large amounts of electrical energy are converted into heat in the refining process.

The combustion of waste pulping liquors, such as black liquor produced in the kraft process is undertaken in a chemical recovery furnace. As the essential function of the unit is the recovery of chemicals, the steam generated varies according to the liquor firing rate and other factors. The recovery furnace normally provides the base load in meeting mill steam requirements, with the balance of the steam generated in one or more power boilers. The chemical recovery furnace system is described in Section 11.

The term power boiler applies to the steam generation units that burn wood refuse or fossil fuels or a combination of both. The power boiler consists of a fuel feeding system, a combustion system, a steam generation unit and an emission control system.

Wood refuse fuel, normally known as hog fuel, consists of wood wastes of all types and may include sawdust, sticks, chip fines and overs, cutoffs, as well as bark and wood residues from wood harvesting, handling and preparation processes.

A detailed survey of the types of boilers installed in the pulp and paper industry in Canada is included in Report EPS 3-AP-77-6.

12.2 Steam Plant

Newer mills have a single steam plant containing the power boiler and, in kraft or sulphite mills with recovery systems, a recovery furnace with a central control room serving all boilers for the operators who have the responsibility to generate steam to meet the demands of mill departments. Accordingly, boiler plant auxilliary equipment such as stacks, boiler feedwater treatment, sewer systems, may serve one or more units. The boiler feedwater treatment produces filter backwash and other effluents, such as brine, depending on the treatment system employed. This effluent is usually an insignificant proportion of the mill total effluent.

12.3 Power Boiler

The functions of the power boiler fuel feeding and combustion system are

- to control introduction of fuel to the combustion zone,
- to combine the fuel with the air to achieve nearly complete combustion,
- to maintain ignition,
- to permit ash removal and to allow the gaseous products to leave the reaction zone with a minimum of entrained particulate material.

Most power boilers designed to accept hog fuel use one or more variations of pile burning, such as grate burning on stationary, travelling or sloping grates, or in refractory-lined cells, typically of the dutch oven type. Although alternative methods of combustion for wood refuse fuel exist, such as suspension firing, fluidised bed burning or gasification and pyrolysis, economic or technical factors have prevented their widespread acceptance to date.

Because of availability, low cost, and convenience, fossil fuels such as coal and oil were historically the preferred fuels for power boilers, with hog fuel, either alone or more generally in combination with fossil fuels, being introduced primarily as a means of disposing of wood refuse and bark. Many older power boilers currently use wood refuse fuel consisting primarily of bark from wet debarking operations, which requires troublesome pressing and size reduction stages to yield a low heat content fuel that provides poor response to changes in steam demand. Variations in steam demand therefore must still be met using fossil fuels.

In more modern installations, improvements in boiler design such as better firing and combustion methods combined with drier fuel due to the introduction of dry debarking and improved hog fuel preparation, have made wood refuse a more convenient fuel and, of course, the fuel itself is cheap when compared to current prices for fossil fuel. Recent developments which have improved the economics of wood refuse as an energy source include wood refuse drying systems using boiler flue gas to raise the fuel value and pelletizing of wood refuse to reduce transportation and handling costs.

An elevation view of a modern power boiler designed to burn hog fuel, generating 90 000 kg/h steam at 3 500 kPa/345°C and equipped with travelling grate and a two-stage multiple cyclone, is presented in Figure 35. The range of typical process steam consumption for pulp mills alone is presented in Table 14.

TABLE 14 TOTAL PULPING PROCESS STEAM DEMAND

Process	Range of Steam Demand (kg/t pulp)
Unbleached Kraft	7 000 to 10 000
Bleached Kraft	9 000 to 12 000
Neutral Sulphite Semichemical	7 000 to 9 000
Unbleached Sulphite	5 000 to 6 000

Because older mills are concentrated in Eastern Canada, and have grown in stages, multiple relatively small power boilers in the 20 000 to 100 000 kg/h steam production range are frequently encountered. In newer larger mills single power boilers generating 100 000 to 200 000 kg/h steam are more common. In mills without chemical recovery furnaces, a small oil-fired boiler is often provided for emergency use. A modern 700 ADtpd bleached kraft pulp mill would have a recovery furnace and a power boiler of about 220 000 kg/h and 110 000 kg/h design steam output respectively, the latter output based on 75% hog fuel and 25% fossil fuel firing.

In older bleached kraft pulp mills, the recovery furnace typically generates in the order of half the steam required for the process, while in more modern energy efficient bleached kraft pulp mills, the recovery furnace meets 80% or more of requirements.

Typically, a modern 450 ADtpd thermomechanical pulp and newsprint mill will have a power boiler designed for about 100 000 kg/h steam generation.

Based on 1982 costs, a fully erected package oil or gas fired power boiler would cost typically $30 to 50 per kg/h steam generated including all auxiliary equipment. Large field erected wood refuse boilers in the 100 000 to 200 000 kg/h range would cost $200 to 300 per kg/h steam generated on the same basis, but including hog fuel storage, preparation and handling.

12.4 Power Generation

The generation of electric power concurrently with production of steam for process heat, or cogeneration, is increasingly practiced in Canada, particularly in

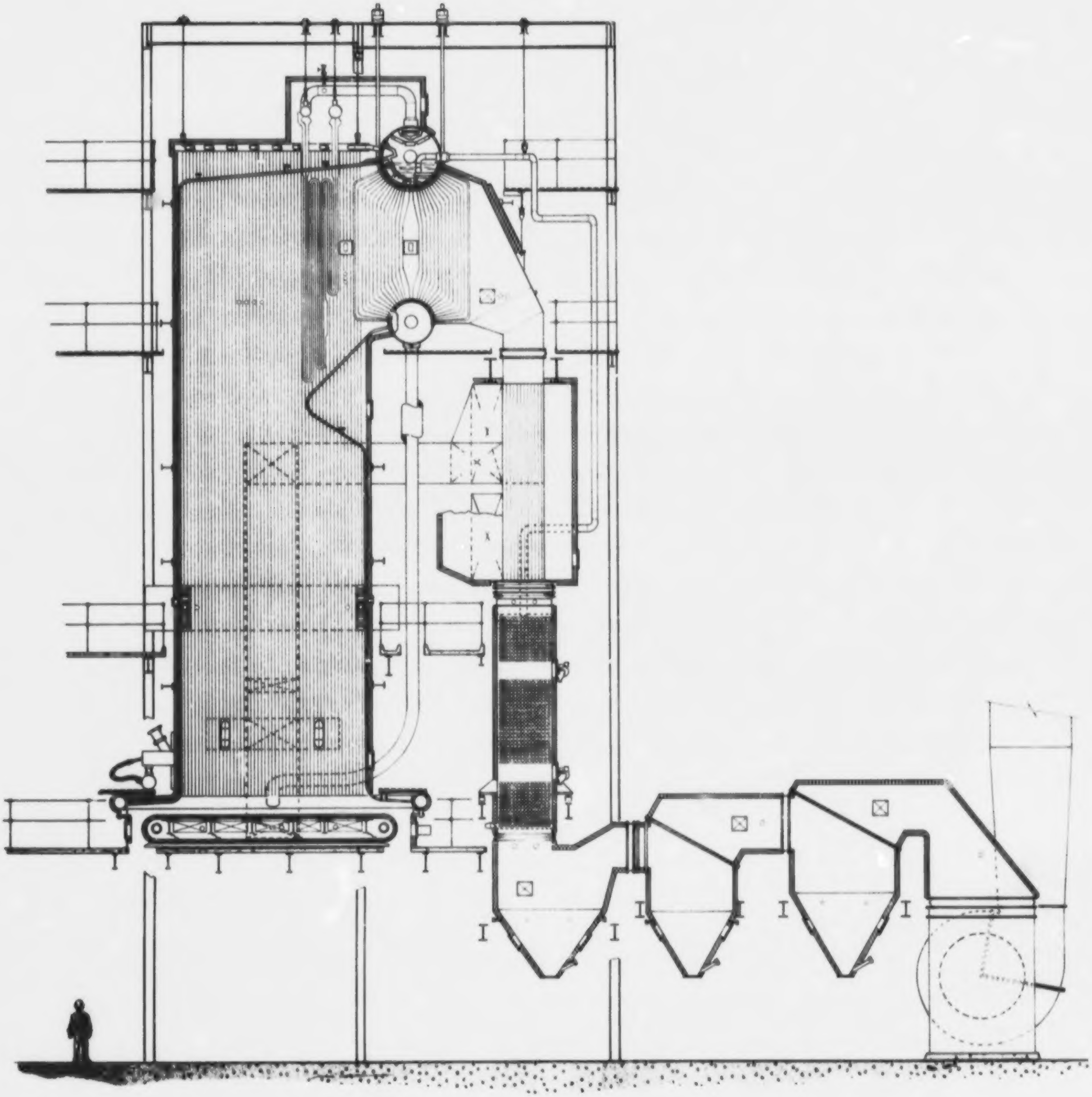

FIGURE 35 HOG FUEL BURNING POWER BOILER
This boiler is equipped with two-stage multiple cyclones.
(Combustion Engineering Canada)

provinces with high utility power costs. In the period of inexpensive oil from the second world war to 1973, power generation by mills was generally uneconomic and many installations that had been running for decades were abandoned because power could be purchased more inexpensively from the utility. The underlying economic factors have now changed, making generation of power quite attractive at many mills, particularly those using back pressure turbines.

In older installations, where mill steam generation pressures are in the 3 000 kPa to 4 500 kPa range with limited superheat, and a significant portion of the steam demand is at 1 500 kPa, opportunities are limited for generating significant quantities of power. In newer power and recovery furnace installations, higher steam generation conditions such as 6 200 kPa at 450°C are frequently selected making a greater pressure drop available to the back pressure steam turbine for power generation.

A back pressure turbine achieves a relatively efficient conversion of 80 percent or more of the heat in the steam to electricity, since full use is made in the mill of the exhaust steam. If the incremental boiler fuel is inexpensive, as is the case for hog fuel, the electricity so produced will be inexpensive.

An alternative turbine configuration where the exhaust steam is condensed by cooling water permits the generation of much larger amounts of power per kilogram steam. However, it is a much less efficient process, and in most cases uneconomic when the alternative of utility power is available.

Environmental consequences of power cogeneration by back pressure turbines relate to the increased use hog or other fuel, whose handling, storage and burning will affect the quantity of atmospheric emissions. In some instances, increased use of hog fuels, particularly those containing bark, reduces or eliminates a landfill disposal problem and the effect is beneficial. Where power is generated in condensing turbines, the additional environmental impact of cooling water discharges has to be considered. One benefit of the current trend toward the installation of large and efficient hog fuel boilers in pulp mills is that they often result in the shutdown of inefficient and polluting waste wood burners at local sawmills.

It is currently the policy of the federal government to encourage the cogeneration of power through a program of grants whenever the fuel for power generation does not use additional conventional fuel resources. On a country-wide basis, one advantage of increasing the use of hog fuel is that it usually replaces sulphur-containing oil and reduces oil imports at some point, perhaps remote from the mill.

12.5 Boiler Emissions and Solid Wastes

The principal atmospheric emissions from power boilers are particulate matter and sulphur dioxide. The source of the sulphur dioxide emissions is the sulphur contained in oil or coal, since the sulphur content of wood refuse and natural gas is insignificant.

Particulate emissions from boilers without air emission control equipment vary from 2 kg/GJ when firing lignite or high ash bituminous coals, to typically 1.5 kg/GJ when wood waste is burned in modern boilers, to approximately 0.05 kg/GJ when heavy oil is fired. Natural gas fuel normally creates no significant particulate emissions.

The rates of uncontrolled emissions are dependent on the types and proportions of the fuel fired, firing rate, burner type, furnace temperature, combustion controls and changes in steam demand. Older power boilers with thick fuel beds or pile burning and poor turbulence in the combustion zone generally produce much higher particulate emissions because of carryover of unburned lighter fuel particles. This phenomenon is inherent in the furnace design and is very difficult to correct. Uncontrolled sulphur dioxide emissions are in the range of 1 to 1.5 kg/GJ, when firing 1 to 2% sulphur fuel.

The non-combustible ash and inert material as well as imperfectly burned fuel particles pass through the boiler, discharging either as bottom ash from the grate area, as heavier fly ash removed in particulate emission control equipment, or with the flue gas stream into the atmosphere.

Typical solid wastes produced are presented in Table 15 for a modern power boiler of 110 000 kg/h output equipped with a spreader stoker wood refuse feed system with windswept spouts, a pinhole grate, and particulate emission control equipment.

12.6 Atmospheric Emission Control Equipment

12.6.1 Particulate Emissions. Wood refuse power boiler particulate emission control equipment most commonly consists of mechanical collectors employing centrifugal separation. These may be multiple cyclones or large diameter cyclones. Under normal operation in newer boilers mechanical collectors generally enable wood fired units to meet typical provincial particulate emission regulations of 225 mg/m^3 at 12% CO_2. However, this equipment may not be sufficient for coastal mills where salts, introduced by the handling of logs in sea water, constitute a significant additional fine particulate load to be removed by the emission control equipment.

Alternative systems for hog fuel fired power boilers include wet scrubbers which provide better performance than mechanical collectors. However, they present the

TABLE 15 HOG FUEL FIRED POWER BOILER SOLID WASTES

Fuel Burned, as fired	45 000 kg/h
Moisture Content	45 - 50%
Steam Generated	110 000 kg/h
Solid Waste Generated	
- grate ash	115 kg/h
- air pollution control equipment	400 kg/h
- particulate emission to stack	50 kg/h

disadvantages of adding water vapour to the gases, which creates a visible plume, and producing a wet sludge often requiring treatment. Maintenance and operating costs are considerably higher than for mechanical systems.

Electrostatic precipitators, which have been traditionally used on chemical recovery furnaces and coal fired boilers, are used in a limited number of installations of wood refuse fired boilers, almost entirely on the west coast. Performance on a salt-free fuel basis is superior to mechanical collectors but operating efficiency is considerably reduced by the presence of salt. Electrostatic precipitator performance is believed to be degraded by the good electrical conductivity of the fly ash, causing particulates to lose charge and be re-entrained into the moving gas stream. Electrostatic precipitators are considerably more expensive to install and maintain than other particulate emission control equipment, which tends also to reduce reliability.

A summary of the relative performances of the three principal particulate emission control systems together with order of magnitude costs is presented in Table 16.

12.6.2 Gaseous Emissions. SO_2 emissions can be controlled by limiting the sulphur content of the coal or oil or by scrubbing the flue gases to remove of SO_2 prior to discharge. The most common method of SO_2 emission control in the pulp and paper industry is the use of coal or oil with suitably low sulphur levels. This is achieved by blending high and low sulphur fuels, although this usually increases fuel costs. While flue gas scrubbers for SO_2 removal are commonly used with the very large boilers of the western American utility industry, they are expensive and only justified because of the lack of low sulphur fuels, particularly coal. In the case of the pulp and paper industry, increased use of wood refuse fuel reduces sulphur dioxide emissions from a mill if the wood waste fuel replaces oil and coal, which contain sulphur.

TABLE 16 COSTS AND PERFORMANCE OF PARTICULATE EMISSION CONTROL EQUIPMENT

Type	Capital Cost installed ($\$/m^3/h$)	Power Consumption ($W/m^3/h$)	Performance (mg/m^3)
Multiple Cyclone	1 - 2	1.5 - 0.4	down to 200
Wet Scrubber	3 - 5	3.0 - 0.6	under 200
Electrostatic Precipitator	5 - 7	0.5 - 1.3	under 200

Kraft chemical recovery furnaces generate SO_2 emissions comparable to very low sulphur oil, so that improved energy conservation tends to reduce kraft mill total SO_2 emissions by decreasing the proportion of steam generated by burning oil or coal.

12.7 Effluents

The power plant uses cooling water for several purposes, and in some cases this is discharged to mill sewers. This usually adds to effluent treatment costs, and the dilution of the effluent tends to be slightly detrimental to the operation of biological treatment plants. However, dilution reduces the toxicity of the effluent measured as described in the Federal Pulp and Paper Effluent Regulations, and this may outweigh the disadvantages. Many mills use all the power plant cooling water in the production process or discharge the excess directly to the receiving water to reduce the hydraulic load on the effluent treatment plant.

The quantities of cooling water discharged may vary from zero to about 25 m^3/t pulp for mills without condensing turbines. The enthalpy of the cooling water discharged from pulp and paper mills is normally insufficient to cause any detrimental effects on receiving waters due to thermal effects. In the rare case where a mill has a condensing turbine, the cooling water flow could be very high, and it may be necessary to consider the effect on receiving water temperature. The suspended solids and BOD contents of the cooling waters are negligible.

Many mills use water to convey boiler ash, and discharges from ash handling systems can be major sources of suspended solids in the mill effluent if the design or operation is inappropriate. In some cases, the ash is discharged to mill effluent treatment systems, which will effectively remove virtually all the suspended solids if the system is correctly designed and operated.

13 WASTE TREATMENT PRACTICES

13.1 Effluent Treatment

The liquid effluent leaving a mill may require treatment before discharge to a body of water or watercourse. Depending on the characteristics of the untreated effluent and regulatory limitations, primary, secondary or even tertiary treatment may be required to reduce the impact of the treated effluent to levels acceptable for the specific environment around the mill.

Pretreatment comprises the initial treatment processes designed to remove grit, coarse material and debris, to neutralise acid or alkaline wastes, and to equalise effluent characteristics and flows by mixing the collected effluent streams and directing occasional large flows or concentrated streams which are a normal part of pulp mill operations to spill tanks or basins.

Primary treatment processes are designed to remove suspended solids from the effluent and normally include the dewatering of the recovered settled solids or sludge to facilitate disposal to landfill or combustion. Primary treatment is a pre-requisite for most secondary treatment processes.

Secondary treatment processes reduce the biodegradable portion of the dissolved organic constituents of the effluent. This biodegradeable portion is expressed as BOD. Biodegradable material added to receiving waters consumes dissolved oxygen, and may cause oxygen depletion and death of fish and other aquatic life. Most secondary treatment processes also reduce toxicity to fish.

Tertiary treatment is the final process of effluent treatment embracing a broad range of processes used to remove further contaminants such as colour, odour, taste, and toxicity from effluents after primary and secondary treatment steps. Tertiary treatment may be used to remove dissolved chemicals and organics, dissolved gases and residual suspended solids and biodegradable material.

In many mills, external effluent treatment processes are installed to treat part or all of the effluent from the mill. In the more recently built mills the effluents are segregated to facilitate and reduce the cost of treatment. For instance, bleach plant effluents from new kraft pulp mills, which contain very little suspended solids, normally bypass the primary treatment process, reducing the size of primary treatment facilities. Cooling water, which would only detract from treatment efficiency, normally bypasses primary and secondary treatment. Woodroom effluents associated with wet debarking are often treated separately prior to being combined with the effluent from the remainder of the mill, and perhaps undergoing further treatment. A typical primary and secondary treatment system flowsheet is shown in Figure 36.

Toilet, washroom and other office liquid wastes in newer mills are collected and treated in separate sanitary sewer systems. Treatment is by established municipal practice, frequently in a package plant. Following final chlorination, the sanitary waste may be added to the mill effluent for common disposal.

In older mills, sanitary sewage is added to the nearest sewer or trench, which can result in pollution of a receiving watercourse with pathogenic bacteria. Conventional treatment of these bacteria is by chlorination or ozonation, but this is not practical because of the high chemical demands of relatively large mill effluent flows. Many mills are steadily modifying their sanitary sewer systems in accordance with modern practice. The general trend is for mills to adopt a schedule similar to that for the local community's improvements in municipal effluent treatment.

13.1.1 Summary of Mill Effluent Characteristics. The mill effluent characteristics vary and depend on the process, production rate, degree of implementation of in-plant effluent reduction measures and the quality of operation. The characteristics of combined untreated effluent typical of common pulp and paper mill operations are presented in Table 17.

TABLE 17 TYPICAL CHARACTERISTICS OF PULP AND PAPER MILL EFFLUENTS

	Flow (m^3/t)	Suspended Solids (kg/t)	BOD (kg/t)
Unbleached Kraft Pulp	10-100	5-50	5-25
Bleached Kraft Pulp	100-240	35-60	30-50
Newsprint Mill (inc. sulphite)	20-150	10-50	40-80
Sulphite without Recovery	150-300	10-50	140-300
Neutral Sulphite Semichemical	10-100	5-25	5-50

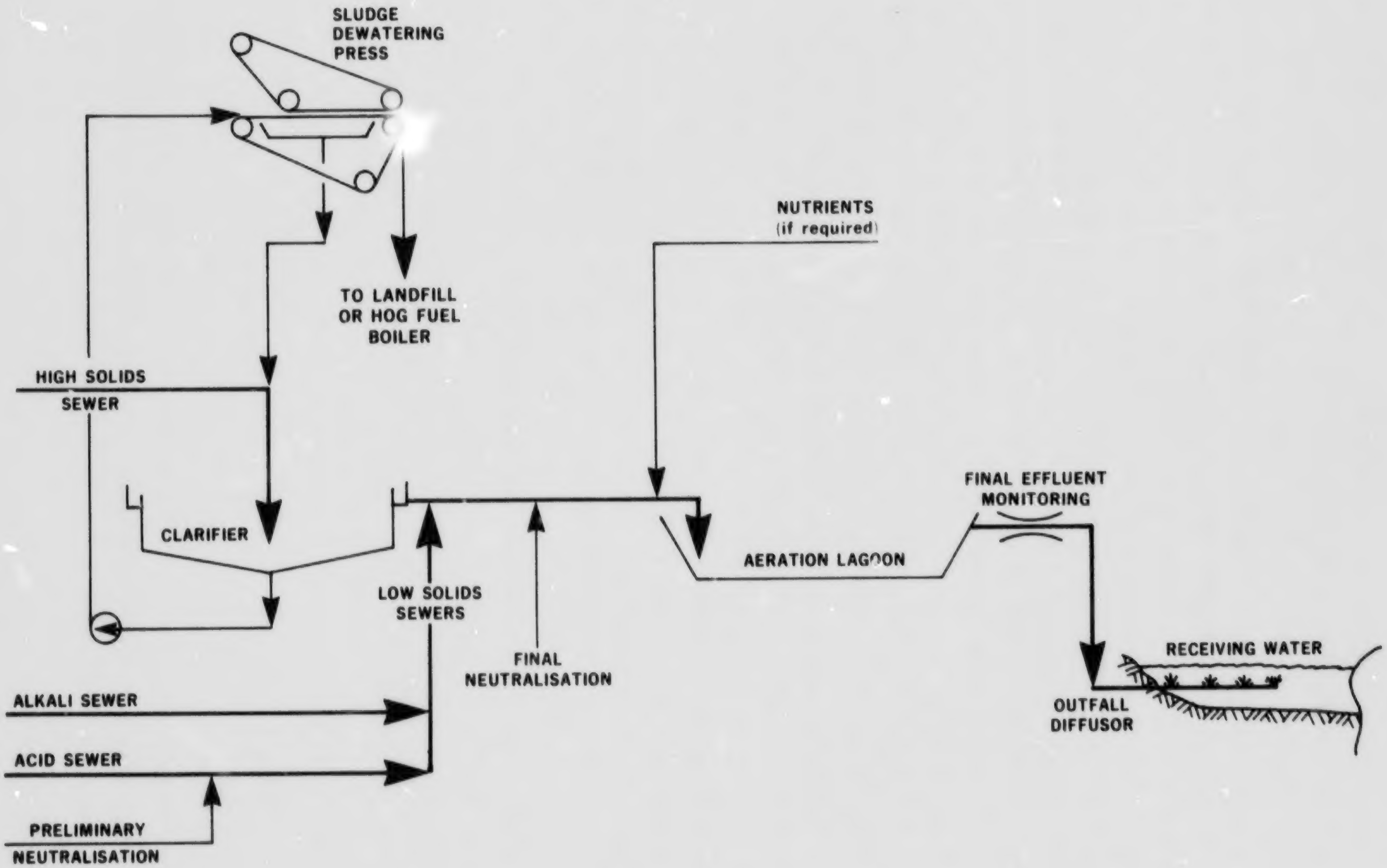
SLUDGE DEWATERING PRESS
TO LANDFILL OR HOG FUEL BOILER
NUTRIENTS (if required)
HIGH SOLIDS SEWER
CLARIFIER
FINAL EFFLUENT MONITORING
AERATION LAGOON
LOW SOLIDS SEWERS
FINAL NEUTRALISATION
RECEIVING WATER
ALKALI SEWER
OUTFALL DIFFUSOR
ACID SEWER
PRELIMINARY NEUTRALISATION

FIGURE 36 TYPICAL EFFLUENT TREATMENT SYSTEM

13.1.2 **Pretreatment.** The common pretreatment methods are grit and debris removal and effluent screening. Inorganic ash, grit from the wood preparation process, sand, and gravel usually must be removed from the waste effluents to reduce abrasion and prevent damage to pumps, piping and solids dewatering equipment. The grit chamber is a gravity settling tank that can be either manually cleaned periodically or cleaned automatically by mechanical means. Bar screens with spaces of 1 to 3 cm are commonly used to remove large debris that might cause clogging of overflow weirs and sludge withdrawal lines. New designs tend to employ mechanically cleaned bar screens.

A second important pretreatment process is the neutralisation of mill effluent. Not only will the pH of the wastewater affect conditions in the receiving streams but extreme pH can cause severe corrosion and adversely affect secondary treatment. Effluent pH should normally be between 6.5 and 8.0 to prevent disturbances in secondary biological treatment systems. The design of the neutralisation method depends on the pH, acidity, and alkalinity of individual sewers as well as their volume. Most bleached kraft mills today have separate acid, alkaline and (essentially neutral pH) high solids sewers. The acid sewer usually contains the effluent from the acid bleaching stages and related chemical preparation plant effluent containing hydrochloric, sulphuric and other acids and has a pH value in the 1 to 3 range. Wastewaters containing ash from power boiler, lime kiln and recovery operations contain large amounts of inorganic alkaline solids. Effluents from kraft pulping operations are alkaline while those from sulphite pulping are acidic. Caustic extraction wastes from the bleach plant are also strongly alkaline.

In kraft pulp mills, effluent neutralisation can be achieved, to a large extent, by using waste chemicals and appropriate mixing of selected effluent streams. Lime mud from the lime kiln scrubber is added to the acid sewer stream at a controlled rate to achieve coarse upward adjustment of the pH. Following mixing with the alkaline sewer stream, which further raises the pH, final adjustment is accomplished by the addition of acid and/or caustic before secondary treatment. In older mills, the absence of segregated sewers and constraints imposed by mill layout may preclude the use of this method of cost-effective neutralisation. A typical kraft pulp mill acid sewer neutralisation system is presented in Figure 37.

Spill basins or tanks in addition to those normally installed within the mill departments are commonly used for temporary storage of concentrated wastes spilled during sudden process upsets. Spills thus contained may be treated separately or metered back at a controlled rate, avoiding sudden shock loads to the subsequent treatment operation.

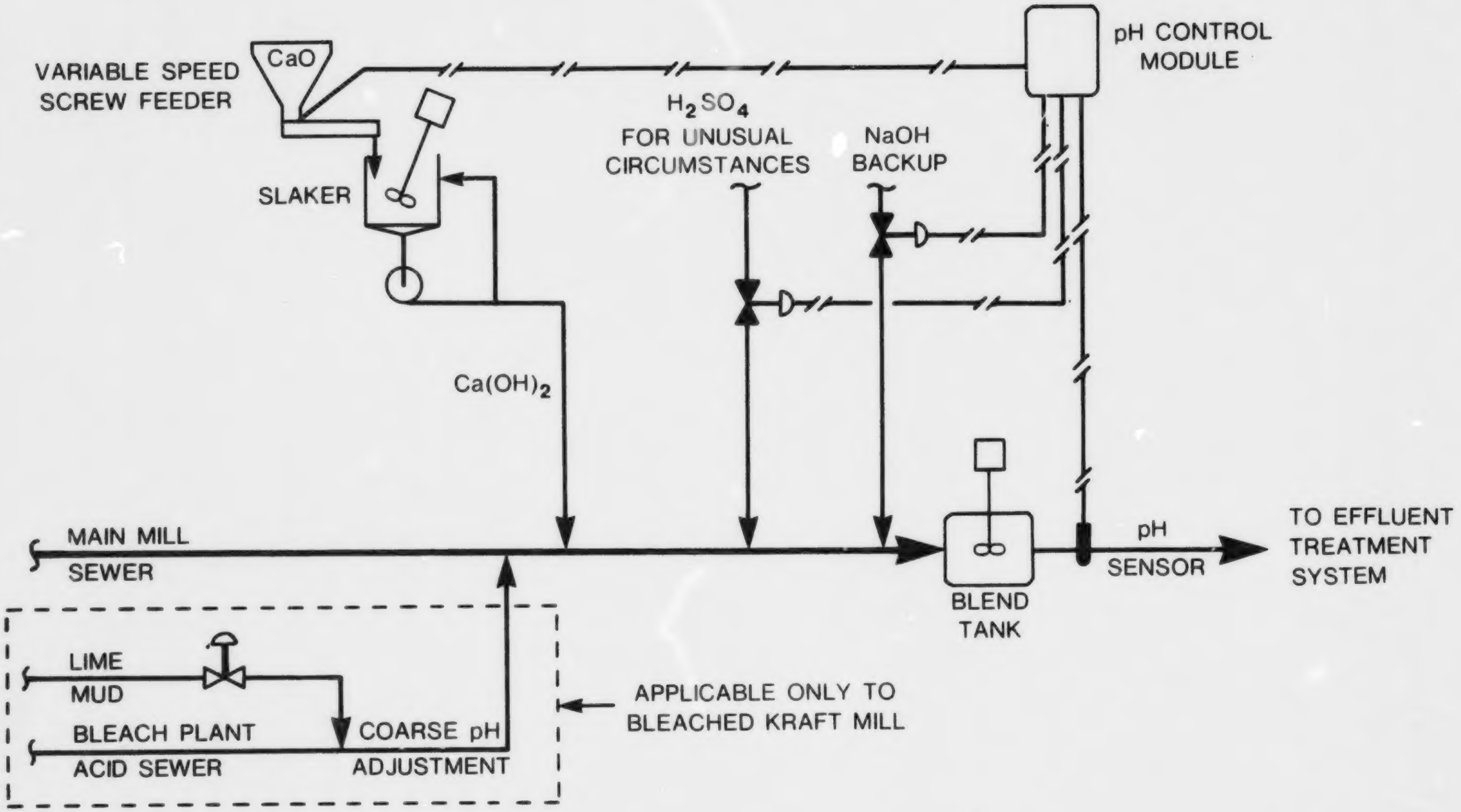
VARIABLE SPEED
SCREW FEEDER
CaO
SLAKER
Ca(OH)$_2$
H_2SO_4
FOR UNUSUAL
CIRCUMSTANCES
NaOH
BACKUP
pH CONTROL
MODULE
MAIN MILL
SEWER
BLEND
TANK
pH
SENSOR
TO EFFLUENT
TREATMENT
SYSTEM
LIME
MUD
BLEACH PLANT
ACID SEWER
COARSE pH
ADJUSTMENT
APPLICABLE ONLY TO
BLEACHED KRAFT MILL

FIGURE 37 KRAFT MILL SEWER NEUTRALISATION SYSTEM

13.1.3 Primary Treatment. Primary treatment is carried out in gravity clarifiers, or in settling basins and, in some instances, in air flotation units. Primary treatment removes 80 to 95% of the settleable portion of the suspended solids. The balance of the suspended solids or unsettleable portion, consisting of colloidal or very fine material, passes through the system and, if it is a substantial fraction of the total, may require chemical addition to promote settling. The settling aids or flocculating chemicals added include alum, ferric chloride and polyelectrolyte. Since part of the effluent BOD is related to the suspended solids in the effluent, primary treatment normally results in a reduction of about 10% of the total BOD.

Primary treatment is commonly accomplished in a gravity clarifier, which consists of a circular tank equipped with sludge removal rakes. The effluent is fed in at the centre and flows radially to the overflow weir located at the periphery. Settled solids deposited on the clarifier floor are raked to the centre by the rotating mechanical raking system and are drawn off and dewatered prior to disposal.

Alternatively settling basins, usually excavation-and-fill earthworks with concrete inlet and outlet structures, may be used. They are normally designed with 6 to 24 hours residence time, allowing settleable solids to deposit on the floor of the basin. They may be lined with clay or a membrane to reduce seepage into the ground. The basins are cleaned out with earth moving equipment. Although they are low in initial cost, settling basins may be costly to clean since there is no convenient means of removing water from the sludge prior to disposal. However, they are very reliable if properly constructed since they do not rely on mechanical equipment. Where site conditions are suitable, the cleanout cost is lower than the cost of operating a primary clarifier. In newer installations, settling basins are often used as a back-up to the primary treatment system for gravity clarification, and also serve as spill basins when two or more are available.

The dewatering of sludge produced by a primary treatment clarifier is normally carried out on belt presses or vacuum filters which raise the sludge consistency from about 2% to 20 to 40%. In some mills where primary sludge is burned along with hog fuel in the power boiler, a further stage of dewatering in a cone or vee press is installed to increase dryness by an additional 5 to 15%. Landfill disposal of sludge is discussed in a subsequent section of this manual.

Disadvantages associated with burning primary treatment sludge include additional abrasive wear inside boilers, and possible slagging problems caused by low melting point components of the inerts in the sludge.

13.1.4 Secondary Treatment. Secondary treatment is designed to remove BOD associated with the dissolved organic materials in the effluent, and normally uses biological processes. The aerated lagoon has been almost universally adopted for secondary treatment by the Canadian pulp and paper industry. Other available methods include activated sludge using either air or oxygen, rotating biological contactors, and trickling filters.

The objectives of secondary treatment are normally to reduce the BOD by 70% to 95% and to render the effluent non-toxic to fish, as defined in the Federal Pulp and Paper Effluent Regulations. A biological treatment process can convert much of the dissolved organic material in mill effluent to water, carbon dioxide or organic suspended solids. In the latter case, it may be necessary to install some equipment to dewater these solids and dispose of them in an environmentally acceptable manner. This part of the treatment process requires as much design and operating effort as the principal biological reaction section.

Biological effluent treatment processes utilise naturally occurring micro-organisms to convert dissolved organic material to environmentally benign materials. The fundamental mechanisms of the process have been discussed at length in many textbooks, and the following explanation is intended only to provide an appreciation of the key factors that affect the design and operation of pulp and paper industry wastewater treatment systems. A detailed treatment of the subject, with numerous references, is presented in Report EPS 3-WP-76-4. Since essentially all systems in use are aerobic (i.e., operate in the presence of oxygen), the following discussion excludes consideration of anaerobic processes.

The micro-organisms are a mixture of bacteria, algae, fungi, protozoa, and other higher forms of life, which continually change to adapt to the effluent characteristics and conditions in the reaction vessel. Bacteria predominate, so their characteristics must be considered when examining the performance of biological waste treatment systems. The majority are from 0.001 to 0.005 mm in size, and they are surrounded by a cytoplasmic membrane through which all organic molecules, which the treatment system is expected to remove from the effluent, must pass.

The materials in pulp and paper effluents which cause the BOD and the toxic properties are primarily organic compounds and have quite a wide range of molecular weights. The smaller molecules are treated preferentially, accounting for the characteristic tendency of biological treatment systems to be more efficient in the treatment of low molecular weight pollutants, such as methanol, than in treating the high molecular weight materials, such as resin acids and chlorinated lignins.

Although the micro-organisms can adapt to changes in effluent quality, it is not uncommon for pulp and paper industry discharges to change more quickly than the micro-organisms can react, which can cause abrupt reductions in the population and the subsequent loss of treatment efficiency.

The micro-organisms float freely in the effluent, and can be detected by conventional suspended solids tests, or visually due to the turbidity they cause. Where the microbiological population is concentrated enough for reasonable rates of effluent treatment, some or most of the organisms will settle to the bottom of the vessel unless maintained in suspension by mechanical agitation.

Essentially, operating the biological treatment process consists of creating the appropriate conditions for a healthy population of micro-organisms to develop and feed on the organic matter in the effluent. Most of the published data and textbooks concerning the design and operation of biological treatment systems concern municipal sewage. The failure of many pulp and paper industry systems to perform as desired can be traced to the use of municipal treatment system design parameters, which are generally inappropriate for pulp and paper industry wastes. The principal parameters are retention time, pH, temperature and supply of sufficient nutrient material.

The pH in the biological reaction vessel must be fairly close to neutral, which normally requires the installation of automatic pH control equipment. Some biological systems have considerable buffering capacity, so that precise pH control is often not required, and the reliability of the system installed is more important than attaining a high degree of precision in control.

The maximum acceptable operating temperature for a biological treatment system is about 35°C. In short retention time systems (under 12 hours) this may require a cooling tower for pulp mill effluent, particularly since the current trend to reduce effluent flows by extensive in-plant recycle generally raises effluent temperatures. Very low temperatures hinder the biological reactions necessary for effective effluent treatment, and this must be considered in designing the longer retention time systems (over about 48 hours) where winter conditions are severe. Experience in Canada has shown that predictions in much of the American literature of complete failure of biological treatment processes in winter are not applicable to pulp and paper industry effluents. Generally the high effluent temperature combined with the characteristic foam blanket prevents the temperature in the treatment system from dropping to unacceptable levels, although BOD reduction efficiencies are normally lower in winter than in summer.

The principal nutrients required are carbon, oxygen, nitrogen and phosphorus. Sufficient carbon is always available, since the objective of the treatment system is normally to remove the organic carbon compounds from the effluent. Oxygen must be supplied by mechanical devices, most commonly surface aerators. Pulp and paper industry effluents are usually deficient in nitrogen and phosphorus, so these materials are added as required to maintain treatment system efficiency.

The retention times in practical biological treatment systems vary from about 2 hours to 20 days, with 4 to 10 days being the most common in the Canadian pulp and paper industry. When designing and operating biological effluent treatment systems, it is essential to appreciate that the response of the system to a change in quality of the raw effluent, or other operating parameter, is normally one to three orders of magnitude slower than the chemical and physical-chemical reactions used in the pulp and paper manufacturing processes. Thus several weeks may be required to evaluate the effect of changes in operating practices or effluent loadings on a six-day retention aerated lagoon. This slow response is an asset with respect to the ability to absorb shock loads, but is an obstacle to effective process control.

The foregoing general discussion of biological treatment applies to all aerobic systems. Further specific points are discussed below in the context of the commonly used processes.

The aerated lagoon commonly provides 3 to 10 days retention of the effluent where, in the presence of dissolved oxygen, nutrients and low concentrations of biological organisms, the biological population feeds on the organic matter in the effluent. The dissolved oxygen is replenished by electrically driven mechanical aerators on the lagoon surface or by diffusers or mixers located on the lagoon bottom using air supplied through a piping system. The classic nutrient requirements of about five parts of nitrogen and one part phosphorous per 100 parts of BOD are frequently met by the addition of urea or ammonia and phosphoric acid in the initial months of lagoon operation. Experience shows that these nutrients recycle themselves in the lagoon sufficiently to render continuous addition unnecessary in many cases. A large proportion of the suspended solids produced by the reaction settle in the lagoon and are consumed by auto-oxidation. One of the key factors in the design and operation of aerated lagoons is to ensure that auto-oxidation takes place so that expensive and difficult cleanout operations can be avoided.

In comparison with the other secondary treatment methods aerated lagoons require a large area of land. However, the lagoons provide distinct advantages over higher rate systems, including:

- ability to absorb shock loads of concentrated effluent without appreciable change in treatment efficiency;
- little or no nutrient addition required except at initial start-up (hence little nutrient discharge);
- lower net settleable solids generation, thus avoiding clarification processes and sludge disposal;
- lower energy consumption due to avoidance of sludge handling;
- better toxicity removal; and
- higher reliability due to the simplicity of the mechanical equipment.

The toxic components of the pulp mill effluents are those which degrade more slowly under the action of the biological organisms. The longer retention time processes, such as the aerated lagoon, therefore provide better toxicity removal than short retention time processes. This can be extremely important in terms of reducing the impact of effluent discharges on the fish and aquatic life of smaller watercourses.

Alternative processes such as activated sludge and rotating biological contactors differ from the aerated lagoon in that a very high concentration of biologically active material is contacted with the organic wastes in the mill effluent in a relatively short time. The rate of BOD reduction is quite rapid, with treatment completed in two to six hours, resulting in much smaller systems. The higher the reaction rate, the more suspended solids are produced. To reduce the suspended solids in the effluent and sustain the biological process, the outlet effluent must be clarified and most of the sludge collected is returned to the treatment system inlet. The excess sludge, about 0.5 - 1 kg solids/kg BOD removed, must be dewatered and disposed of effectively, which may require significant quantities of energy and chemicals. A flow schematic of an activated sludge process is presented in Figure 38.

The activated sludge process for BOD reduction using either air or oxygen can be more economic than aerated lagoons where land area is limited. Several kraft mills, board mills and deinking plants in the U.S.A. have adopted this method for treatment of effluents, but the process is little used in Canada. Most mills have sufficient land available for aerated lagoons and prefer their superior toxicity reduction capabilities relative to activated sludge systems.

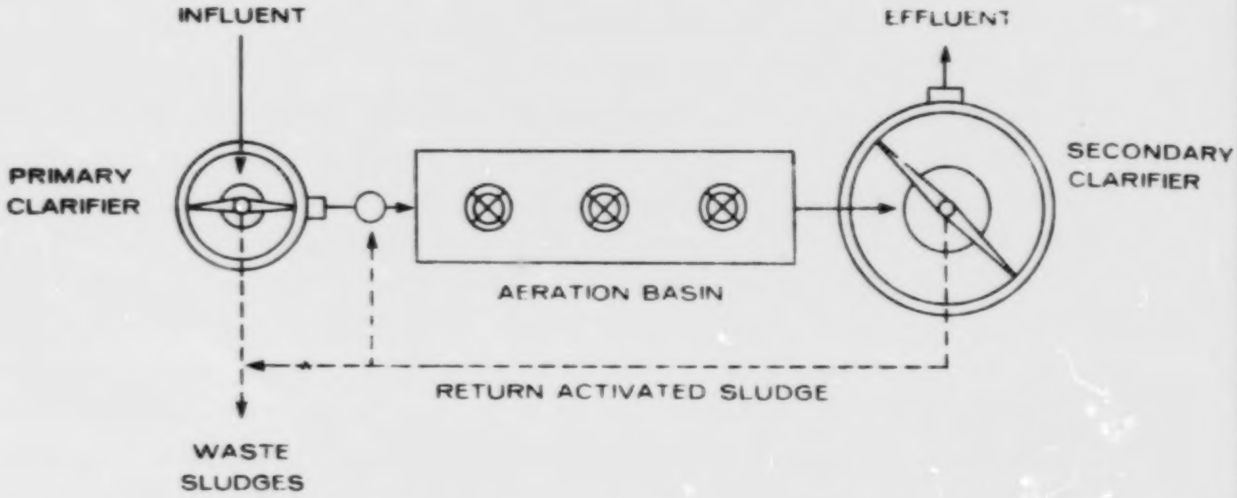

FIGURE 38 ACTIVATED SLUDGE SYSTEM FLOWSHEET

High rate biological systems were generally developed for treatment of municipal effluents. In theory they are capable of higher BOD removal efficiencies than the low rate aerated lagoon systems, but operating experience in the pulp and paper industry has been disappointing, principally due to the wide variations in raw effluent quality which are characteristic of these wastes. There is much evidence that toxicity removal in the activated sludge process is generally inferior to that in a low rate system.

The aeration processes used in secondary treatment of pulp mill waste waters results in the creation of foam, which has a beneficial blanketing effect in retaining heat in lagoons in cold climates. This foam is normally removed prior to discharge of the treated effluent to the watercourse by using submerged outlets and avoiding foam producing drops and partially filled pipe flows.

13.1.5 **Tertiary Treatment.** The components remaining in the effluent after primary and secondary treatment are residual suspended solids, residual BOD, colour and materials resulting in lethal or sublethal toxicity, odour, and taste.

Tertiary treatment processes designed for the reduction or removal of these remaining components are generally costly to operate, and include:

- activated carbon absorption,
- massive lime treatment, and
- foam separation.

Only a few Canadian mills with specialised problems have installed tertiary treatment systems.

13.1.6 Outfalls and Treated Effluent Disposal. The method of discharging a mill effluent to the receiving water has a significant effect on its environmental impact. It usually desirable to dilute the effluent as quickly as possible after discharge, and almost always necessary to take measures to reduce or eliminate visible foam and colour on the surface of the receiving water.

The location must be carefully selected, and in some cases it is more effective to expend resources on the construction of an environmentally effective outfall than on a waste treatment plant. An obvious example is the case of a mill located near the mouth of a small river, where an outfall, perhaps as much as a few kilometres long, to discharge the effluent to the sea is more effective in minimizing the environmental impact of the mill than any degree of effluent treatment, however efficient.

Outfall selection and design is very site-specific, so it is difficult to provide any general guidelines. The efficiency of dilution must be evaluated, with due consideration of the effects of currents and density differences between the effluent and the receiving waters.

In addition to satisfying environmental criteria, the outfall site must be suitable for the construction of a structurally sound installation. The performance of an outfall is very reliable (more so than any effluent treatment system), but structural failures are sometimes difficult to correct, particularly in Canadian winter conditions.

13.1.7 Sampling, Monitoring, and Analytical Methods. Sampling and monitoring procedures have been defined for mill effluents, as described in the Pulp and Paper Effluent Regulations (EPS 1-WP-72-1). In addition to these regulatory requirements, most mills perform some internal sampling and monitoring to be able to assign responsibilities for effluents and, in particular, to identify and minimize dumps and spills. The information collected is also frequently used for design and optimisation of in-plant effluent control systems.

Effluent toxicity is defined differently by various authorities, but the relevant standards in Canada all use some type of mortality test on fish. The federal guidelines are based on an acute toxicity test defined in report number EPS 1-WP-80-1.

The other parameters commonly used for definition of effluent quality and for regulations are determined according to Standard Methods for the Examination of Water and Wastewater, published by the American Public Health Association. This is updated and republished every few years, and the latest edition should always be used. At the time of writing, the current edition is the fifteenth.

13.1.8 Effluent Treatment Costs. Typical capital costs for effluent treatment in relatively recently constructed mills are presented in Table 18. These costs are presented for illustrative purposes only and may vary substantially depending on land availability, need for pumping, layout and complexity of sewers, soil conditions and terrain and other specifics of a given mill. The addition of an effluent treatment system to an older, existing mill would generally be more expensive, since the mill-site would not normally have been selected with a view to effluent treatment system installation. All costs have been adjusted to 1982 basis.

TABLE 18 CAPITAL COSTS OF EFFLUENT TREATMENT SYSTEMS

Product	Baled Pulp	Linerboard	Newsprint	Newsprint
Process	Bleached Softwood Kraft	Unbleached Kraft	Groundwood Sulphite	TMP
Production ADtpd	700	700	750	500
Untreated Effluent				
- flow m^3/d	60 000	35 000	75 000	35 000
- SS kg/d	25 000	15 000	24 000	15 000
- BOD kg/d	20 000	10 000	30 000	13 000
Treatment Costs (in millions of dollars)				
- primary $	4	3	5	3
- secondary $	12	7	15	9
TOTAL $	16	10	20	12

13.2 Control of Atmospheric Emissions

In most cases, control of atmospheric emissions is accomplished either by equipment installed directly on, or adjacent to the source, or by special operating techniques and design of the source equipment. These aspects have been discussed in Sections 5 to 12 of this report. This section summarizes total emissions and discusses certain items which are better treated on a mill-wide basis than by department.

13.2.1 Atmospheric Emission Regulations. The federal guidelines have been discussed in Section 2.3 and are summarised in Table 19. Other miscellaneous regulations applicable to the industry are summarised in Table 20.

The provincial objectives of British Columbia are less stringent for existing mills, for all types of emissions, than the limits for existing mills in Washington and Florida. All mills must, however, eventually attain the "new mill" control limits. In Sweden, the limits for existing mills are relaxed only for particulates from both sulphite and kraft mills, although greater variance in observing the limits is granted to existing mills. Examples of increasingly restrictive limits for existing mills within specified time periods are those in the Washington State regulations and, to some extent, those implied in British Columbia's objectives.

13.2.2 Sources and Control of Atmospheric Emissions. Tables 21 and 22 summarise the total pulp manufacturing process emissions reported by kraft and sulphite mills in 1973/74. Bleach plant emissions are shown in Table 12. Note that many of the emission measuring techniques used in the early 1970s for TRS are now known to be inadequate and generally understated emission rates, particularly at low concentrations. Current emissions are lower, probably by a factor of around 25%, than those reported in Tables 21 and 22, but no national inventory is available.

The other principal source of atmospheric emissions is the steam and power generation plant. This is discussed in detail in Section 12. Due to the wide variation in local practices, fuels and requirements, it is not possible to relate the emissions to mill product or size.

13.2.3 Monitoring and Analysis. It is generally much more expensive and time-consuming to determine the rate of emission of atmospheric discharges than the rate of effluent discharges. With the exception of sulphur dioxide, no automatic equipment is yet available that is capable of measuring the discharge rate of the common pulp industry atmospheric pollutants with sufficient reliability for regulatory control, although several systems are available that are useful as on-line monitors to warn operators of unusually high emissions.

Regulatory compliance testing is generally performed by a team of three experts who perform a series of three tests in accordance with one or more of the following standards:

1) Particulate emission monitoring is based on methods described in report EPS 1-AP-74-1.

TABLE 19 FEDERAL GUIDELINES FOR ATMOSPHERIC EMISSIONS FROM NEW PLANTS

	Maximum Emissions (kg/ADt pulp)
Kraft mills	
Particulates	
Recovery Furnace	2.5
Lime Kiln	0.5
Smelt Dissolving Tank	0.25
TRS	
Recovery Furnace	0.15
Digester, MEE, Condensate Stripping	0.015
Lime Kiln, Smelt Dissolving Tank, Brown Stock Washers, Black Liquor Oxidation	0.225
Sulphite mills	
Particulates	2.5
Sulphur Dioxide	10.0
Steam and power boilers	
Particulates (corrected to 12% CO_2)	
Coal Fired	230 mg/m^3
Combination Fired	340 mg/m^3
Oil Fired	160 mg/m^3

TABLE 20 PROVINCIAL AND FOREIGN REGULATIONS AND GUIDELINES FOR ATMOSPHERIC EMISSIONS

	B.C. Objectives				Florida		Sweden	
	New	Existing	Alta.	Wash.	New	Old	New	Old
Kraft pulp mills								
Recovery Boiler								
- TRS as Sulphur (kg/t)			0.25	0.25				
- H_2S (ppm)	6.5	26			1.0*	17.5	10	10
Other Sources								
- TRS as Sulphur (kg/t)	0.225	0.35						
Particulates								
Recovery Furnace								
(mg/m^3)	250	500					250	500
(kg/t)			2	2	1.5	1.5		
Lime Kiln								
(mg/m^3)	250	250					250	250
(kg/t)			0.5	0.5				
Smelt Tank (kg/t)	0.2	0.4		0.5				
Hog Boilers								
(mg/m^3)	250	250					500	500
(kg/t)				0.8-2.5				
Sulphite mills								
Particulates (mg/m^3)	250						250	500
SO_2 (kg/t)	10						10	20

* No mill has ever complied with this regulation

TABLE 21 KRAFT MILL EMISSIONS OF PARTICULATES, TRS, and SO_2

	kg/ADt Pulp*		
	Particulate	TRS	SO_2
Recovery Furnaces			
Number of mills reporting	39	31	21
Average	8.7	3.9	2.1
Median	4.5	1.3	1.2
Maximum	54	20.7	12.8
Minimum	0.35	0.007	0.1
Smelt Dissolving Tanks			
Number of mills reporting	28	24	1
Average	1	0.04	0.15
Median	0.6	0.03	N/A
Maximum	4.1	0.25	N/A
Minimum	0.04	0.004	N/A
Causticisers			
Number of mills reporting	4	6	
Average	0.25	0.001	
Maximum	0.75	0.004	
Minimum	0.005	0	
Lime Kiln			
Number of mills reporting	35	26	12
Average	0.72	0.12	0.25
Median	0.45	0.09	0.08
Maximum	6.3	1.5	2
Minimum	0.04	0.001	0.01

* Data extracted from questionnaire discussed in Report EPS 3-AP-77-6 and refer to Canadian mills.

TABLE 22 KRAFT MILL EMISSIONS FROM "TRS ONLY" SOURCES

	Total Reduced Sulphur* (kg/ADt pulp)			
	Digester	Knotter and Washer	Black Liquor Oxidation	Multiple-Effect Evaporator
Number of mills reporting	5	18	9	10
Average	0.9	0.1	0.07	0.45
Median	0.43	0.7	0.05	0.31
Maximum	2.25	0.39	0.28	1.2
Minimum	0.12	0.01	0.02	0.03

* Reported data are from mills with no emission control. Data extracted from questionnaire in Report EPS 3-AP-77-6 and refer to Canadian mills.

2) Sulphur dioxide monitoring is based on methods described in report EPS 1-AP-74-3.

3) Nitrogen oxide emission monitoring is based on methods described in report EPS 1-AP-77-3.

TRS emission monitoring has been performed in several ways, but presumably will follow a draft reference method which is expected to be finalised by EPS in 1983. Several other standards exist, including some by the Canadian Standards Association, and some mills have used U.S. methods in the past, but this practice is declining.

Whereas it is normal practice for mill laboratories to perform their own effluent monitoring, it is more common for outside specialists to be engaged to measure atmospheric emissions, principally due to the high cost of training and maintaining a competent team for the essentially intermittent work of stack emission measurement.

13.2.4 Odour Control and Dispersion of Atmospheric Pollutants. Most of the regulations intended to reduce odour around pulp mills, except those of Ontario, are based on emission levels rather than on ground level concentrations. However, the impact of any TRS emission on ground level concentrations is often more dependent on the elevation, temperature and velocity of emission than on the quantity of malodourous gases emitted. At a pulp mill with a typical arrangement of stacks, 1 kg of TRS gas emitted from a low-elevation cool vent can have over one thousand times the effect on ambient concentrations of TRS at ground level than the same kilogram emitted from a high, hot stack, such as from a recovery furnace.

The current state-of-the-art of mathematical modelling for prediction of atmospheric dispersion of stack emissions is sufficiently advanced to allow different stack and vent arrangements to be compared for any mill-site, even in complicated terrain. These models often require fairly large computers, which often limited application in the past, but this is not a significant factor today due to the dramatic reduction in computer costs.

13.3 Solid Waste Handling and Disposal

13.3.1 Sources of Solid Waste. In terms of quantity, bark constitutes by far the greater portion of the solid waste generated by pulp and paper mills. In a kraft mill, bark tonnage to be disposed of constitutes in the order of 30% of the pulp produced if the mill debarks 100% of its wood supply on site. However, many kraft and other mills have some or all wood delivered in the form of chips, so the quantity of bark to be disposed of is often much less.

The sources and amounts of solid waste generated in various mill departments have been described within the appropriate sections of this manual. In summary, the solid waste that may be produced in a mill are, by department:

Woodroom	-	bark, stones, gravel, sand
Chip receiving and handling	-	fines, sticks, frozen lumps and overs
Pulp mill	-	knots, dumped chips
Pulp/paper machine	-	cleaner rejects
Boiler plant	-	bottom ash, fly ash
Effluent treatment	-	primary clarifier sludge, trash,
Finishing plant, shops, stores, offices, laboratories	-	miscellaneous refuse

In addition, in kraft pulping, there are grits and dregs from the recausticising department.

The combustible portion of the solid waste, including bark, chip fines and overs, clarifier sludge and the like, is frequently burned for recovery of the heat content and to avoid the cost of landfill disposal.

13.3.2 Disposal Methods. In former times, the dumping of bark on mill property, often adjacent to the mill or town site, created bark piles of truly gigantic proportions, which in some cases still exist. These piles are often poorly located and create water pollution because of the highly concentrated BOD and toxicity of the bark leachates.

The disposal of any mill solid waste, whether containing a combustible component or not, now requires appropriate disposal methods to meet regulatory requirements which generally include:

- criteria for the site proximity to roads, highways, homes and other structures, watercourses and lakes;
- soils investigation, indicating soil permeability;
- establishment of test wells;
- determination of flow, depth, and quality of groundwater;
- description of the sources, amounts of waste and disposal schedule;
- control of leachate and monitoring of groundwater;
- progressive development including layering and final earth covering of the solid waste to restore land to its original surface condition.

14 SPECIAL TOPICS

This section of the manual discusses various topics that could not be appropriately covered in the earlier sections, principally because they apply to two or more of the major mill departmental divisions.

14.1 In-plant Control vs External Treatment

In-plant control measures are generally considered to refer to those environmental protection measures that rely principally on modifications to production equipment or process control systems, or that rely on the selection of inherently "low-pollution" processes or equipment, with the objective of reducing discharges to the local environment whether they be effluents, air emissions or solid waste. In-plant control measures are also termed pollution control at source.

External treatment refers to those environmental protection measures that rely principally on the addition of special environmental protection systems to the production system to treat wastes in order to improve the quality of the discharge. These pollution control systems are often installed separately from the mill, typical examples being clarifiers and secondary treatment systems. Equipment such as condensate stripping systems and particulate emission control devices on power boilers are also external treatment devices, treating particular, segregated streams, although they are invariably installed physically within the mill.

Two extremes of philosophy in design can be represented by either total integration or total separation of effluent control functions and production processes. An example of the first is the concept of an "effluent-free" mill discussed in Section 14.5 discharging only solid and gaseous wastes and using extensive, new in-plant effluent control technology. The second optimizes the economics of production in isolation, relying on comprehensive external treatment for environmental acceptability and is most closely approached by some mills in the southern U.S. Between these extremes lies the present day mill, with innumerable special design and operating features to meet environmental standards with minimum cost and operating restrictions.

In-plant process modifications for effluent quality control are usually special solutions to specific plant situations. Past, present and future directions of a plant all impose their constraints on the applicability of a particular strategy. In-plant measures have always been used by the industry to some extent, and are now practiced extensively due to a combination of regulatory pressure and developing technology. For example, a loss of 5% of the circulating black liquor flow was not uncommon 30 years ago, whereas losses under 1% are achieved today by the use of better washing systems and operating techniques.

14.1.1 Effluent Sources. All water introduced into the process stream except what is evaporated or transported out with solid waste or product becomes effluent. The uses of process water and the sources of its contamination include the following:

- carry off of reaction products;
- purging of impurities introduced with raw material;
- rejection of excessively degraded product material;
- inefficiency of separation of product from process streams;
- process upset, overload, or spill; and
- process equipment wash-up or clean-out.

Most effluents in the pulp and paper industry are generated within these broad categories.

14.1.2 Human Factor. Even the most elegant plant design for pollution control requires skillful management, operation, and maintenance. The individual employee's attitude towards pollution abatement is important. If the attitude is that pollution control is someone else's responsibility and/or should be controlled solely by massive capital spending, effective management of effluent quality becomes significantly more difficult and costly. This attitude is in many instances fostered by overly optimistic objectives associated with abatement practices and policies that become inconvenient at the first production crisis. In-plant control methods are especially sensitive to such attitudes, due to the direct relationship between production and effluent control processes.

Realistic standards that can receive total commitment from management and plant employees provide a basis for continuing education on the environmental consequences of undesirable operating and maintenance practices and promote employee involvement. Any deviation from the standards established will quickly erode this involvement and make consistent performance of in-plant measures for effluent quantity control difficult to maintain.

14.1.3 Effluent Recycle and Reuse. The volume of a typical process-related effluent is too high for convenient recycle. It is often possible, however, to recycle selected waste streams within the process unit. Also, effluent from one process unit may be of suitable quality for reuse in a different process unit, replacing fresh water. Often one or more properties of a potential recycle stream are not compatible with the process where recycle or reuse is contemplated and some upgrading or internal treatment is then necessary. This internal treatment may be part of the existing mill equipment. Occasionally both the opportunity and economic advantage exists to change processes altogether.

Intermittent effluent quality problems arise due to process upset, overload or maintenance requirements that interfere with recycle and reuse. The general in-plant solution is to collect and to store the results of these upsets.

Unexpected new problems can arise if the mass and energy balance and potential chemical reactions of a proposed process stream recycle are not thoroughly analyzed. It has often been found that an effluent was an important outlet for a previously inconsequential component. Soluble salts increase in concentration and accelerate corrosion. Sparingly soluble salts exceed their concentration limits and form scale. Changes in pH may precipitate lignin and pitch, or stabilize foams. Heavy metals catalyse brightness reversion or bleaching chemical degradation. Increased nutrient concentration can accelerate slime growth. A trace organic oil or soap may accumulate in a particular vessel. Temperatures may rise above the limits acceptable for a specific process. On the positive side, recycle of process effluents sometimes results in substantial energy economies and/or modest recovery of useful chemicals or fibre. Analysis of each unique situation is essential to identify potential problems and practical limits on recycle.

14.1.4 In-plant Environmental Protection Measures. In most cases, the technical and financial analyses are complicated and time consuming, but the following comments are generally valid.

The capital cost of in-plant measures is roughly equal to that of external measures for suspended solids discharge reduction, but the in-plant system usually consumes less energy and has lower operating costs. It is technologically simpler and less expensive to implement effective in-plant measures in new mills or during major reconstruction than in existing installations.

For new mills or major reconstruction, the most successful in-plant environmental protection measures are those that are planned into the process from the original concept and are fully integrated with the production process. A major difficulty in implementing advanced in-plant measures (or introducing new technology) in new mills is that the design process has to be completed rapidly to avoid unacceptable delays in the project, and any complex technical studies tend to introduce delays.

In the case of existing mills or mill departments, the most successful in-plant environmental protection measures have been the result of a technically sound overall plan, implemented step by step so that the results of each modification to the process or equipment can be evaluated and, more importantly, the inevitable unforseen problems resolved, before embarking on further modifications.

The following specific in-plant environmental protection measures have been discussed under the appropriate sections of this manual:

- Use of dry barking to eliminate woodroom effluent.
- Recycle of barker effluent to reduce volume of effluent.
- Recovery of bull-screen rejects in stone groundwood mills.
- Increased white water recycle in all types of mills.
- Improved pulp washing efficiency in kraft mills.
- Use of pressure screens instead of open screens to reduce foam overflows.
- Low-odour type recovery furnaces.
- Improved combustion efficiency in hog-fuel boilers to reduce emissions of carbon particulate or fly ash.
- Installation of otherwise un-economic chemical recovery systems in sulphite mills.
- Bleach plant filtrate reuse.
- Oxygen bleaching.
- Modifications to bleaching sequences to reduce colour or BOD.

14.2 Control of Accidental Losses

14.2.1 Sources. Accidental losses are defined as discharges to the environment caused by abnormal operating conditions which are in excess of the discharges which occur when the process is operating normally. They are usually caused by equipment malfunctions or human error (including errors by the mill designer who failed to foresee a particular set of operating conditions). It is inevitable that some accidental losses will take place, since neither human beings nor equipment are 100% reliable, so it is essential to include appropriate allowances when planning environmental protection systems.

Very little solid data is available on the extent of accidental losses, partly due to operators' natural reluctance to advertise their mistakes, and also due to the difficulty of measuring the actual quantities. In some mills with very tightly closed process cycles and low normal losses, the accidental losses can be as much as 60% of the monthly averages. A range of about 20 - 30% is probably typical except for mills with very high continuous discharges. In some cases these accidental losses can be spectacular and can cause environmental damage or extreme public reaction.

It is convenient to divide accidental losses into two classes, spills and dumps. Spills consist of overflows, leaks etc. that occur more or less instantaneously. Dumps are discharges of effluent which are deliberately caused by operator action. Often the operator has no other choice. For example, if the suction valve of a pump is jammed by a wooden plank, it may be impossible to pump the tank out to gain access to clear the blockage, and there is no alternative but dump the tank to the sewer in many mills. Dumps can also be caused by lack of operator knowledge or environmental concern, and by failure to plan maintenance shutdowns so that the levels in tanks which must be entered are low.

14.2.2 Design for Control of Accidental Losses. The first step in controlling accidental losses is to design and build the plant in accordance with good engineering practices. Equipment that is mis-applied fails relatively frequently, often causing accidental losses to sewer. At the design stage, it is essential to evaluate the effects of all the likely modes of equipment failure on the overall mill process, since failure in one department is frequently the cause of spills in others. Extensive experience is available on the failure rates of all the conventional equipment, but risk analyses on the overall system are rarely included in mill design due to the time required. Recently developed process simulation systems facilitate computer modelling of mill operations, which allows the mill designer to make effective use of the available knowledge on individual equipment failures and incorporate suitable spill control features in the mill design.

Adequate intermediate storage for process chemicals and partially manufactured product (as discussed in Section 14.2.3) is important if accidental losses are to be minimised.

Good design and adequate storage facilities are usually sufficient to eliminate significant accidental discharges to the environment. They are also sufficient to control accidental discharges to sewer in many mills which have generously sized waste treatment systems. However mills that wish to comply with regulations without external effluent treatment or that have marginally sized treatment systems normally install spill recovery facilities in the higher risk areas of the mill.

The frequency of accidental losses can be reduced, although not eliminated, by the intelligent interconnection of tanks, the installation of standby pumps, and the provision of spill sumps. New mills are usually superior to older installations in this respect, although major improvements can be achieved in some older mills.

Demands for improved working conditions in the 1960s led to the practice of installing generously sized floor drains at all potential overflow points. Unfortunately this made spills less visible to operators and supervisors, and removed one disincentive to sloppy operating practices. Recently several companies have adopted the policy that the mill layout should make spills visible and even sometimes inconvenient by installing floor drains for continuous effluent streams only. Complex floor drainage systems are expensive, so this approach can reduce capital costs. This is generally desirable, provided that the inconvenience does not extend to a health hazard or risk damaging equipment.

Substantial reductions in effluent discharges can often be achieved by installing collection sumps at key points in the mill to recover overflows and leaks from tanks and equipment. In some cases these can be effectively implemented by segregating certain of the floor trenches, which exist in most process areas, and routing them to the spill collection sump. However, in most cases contamination of the recovered material or excessive dilution by clean water prevents such a simple solution and special piping must be installed.

The material collected in the spill sump must be returned to the process system, either directly or after storage in a spill collection tank pending analysis and a decision on the best time and location for its re-use. In some cases, it is most appropriate to discharge the collected spill slowly to the sewer.

Generally, the majority of spills and dumps occur in a relatively restricted area of the mill, and it is normally in these key areas that accidental loss recovery systems can be effective. Table 23 is a list of the areas where such recovery systems are commonly installed, together with the most popular points of re-introduction to the process.

White water spills are characterised by high volumes and relatively low suspended solids content. It is often impractical to install sufficient storage capacity to contain the larger white water spills, but suspended solids discharges can be reduced by ensuring that whenever there is a large excess of white water, the lowest possible consistency is discharged to sewer. This requires suitably defined operating procedures and instrumentation.

TABLE 23 ACCIDENTAL LOSS RECOVERY SYSTEMS

Mill Department	Type of Loss	Process Re-entry Point
Groundwood	Stock	Grinder Canal
TMP	Stock	Latency Chest
Kraft	Unwashed stock	Blow tank
Kraft	Washed stock	Screens
Kraft	Black liquor	Weak black liquor storage
Kraft	Partly bleached stock	Ahead of bleach plant
Sulphite	Stock	Blow pits
Sulphite	Red liquor	Weak red liquor storage
Paper mill	Stock	Blend chest

The design of accidental loss prevention and recovery systems is site-specific, particularly with respect to the selection of the locations for re-introduction of the recovered material to the process.

14.2.3 Intermediate Product and Chemical Storage. Ideally, a pulp or paper mill would operate continuously, with the rate of production in all departments adjusted to match each other's needs. However this is impractical due to unforseeable equipment problems as well as the need to shut down certain departments (typically for an eight-hour shift) for periodic maintenance. Some storage is therefore required between each major department, and the adequacy of this storage has an impact on accidental losses. Storage is also required for most materials purchased by the mill, but this has little impact on accidental losses and is not discussed.

In principle, mills with generously sized effluent treatment facilities can comply with effluent quality regulations, even if storage capacities are inadequate. However, there are practical and economic constraints on the size of spill that can be effectively treated by a waste treatment system. A technical and economic compromise between storage, accidental loss prevention, and effluent treatment facilities is necessary in all mills.

All mills where very tightly closed process cycles are used to reduce effluent discharges require storage capacity sufficient for mill staff to diagnose problems and take appropriate corrective action before a major spill occurs. This generally requires storage capacities of around the higher values mentioned below.

There is no absolute mathematical method for selection of the size and location of intermediate process storage tanks, but the following are generally incorporated in modern mill designs.

Kraft mills -
- 8 to 24 hours capacity of storage for washed, unbleached pulp, usually at "high-density" (about 12% consistency).
- 8 to 24 hours capacity each for weak black liquor and strong black liquor.
- 24 hours capacity for white liquor (some of this may be in the white liquor clarifier).
- 12 hours capacity for weak-wash (some of this may be in the lime mud washer).
- Up to 24 hours storage for bleached stock, normally at high-density. The storage capacity is generally highest when a complex installation such as a paper mill follows the bleach plant rather than the relatively simple pulp dryer.

Newsprint and other integrated mills - The major storage installed is for pulp ahead of the paper mill and it is usually of 12 to 24 hours capacity. The bleaching operation in mechanical pulp mills is much simpler than in chemical pulp mills, so storage between pulping and bleaching is not usually required for environmental reasons. Several hours storage between the grinders and the screen room would be desirable but is normally impracticable since the pulp consistency is only about 1% and very large volumes would be required.

Sulphite mills with chemical recovery - Storage capacities similar to those for kraft mills apply, except that a large storage capacity for weak and strong red liquor is even more necessary because of the lower inherent reliability of sulphite evaporaters.

Semichemical pulp mills - These are normally integrated with paper mills (usually corrugating medium) and the relative simplicity of these processes makes stock storage less necessary. Twelve hours capacity between pulp and paper mill can be considered generous for environmental protection purposes.

White water - Some white water storage capacity is required in all mills to minimise discharges to sewer due to intermittent imbalances in the operation. Local requirements vary enormously, but about 1 m^3 per daily tonne of production is normally sufficient.

14.2.4 Operating Practices and Housekeeping. Much of the action required to control accidental losses can be described as good housekeeping or running a tight ship, since many dumps and spills are due to simple errors which are relatively easily avoided. The most advanced technology and exotic equipment is ineffective if it is poorly operated or maintained.

Operating practices and training have an important impact on all aspects of mill operations, but particular attention is required to the control of accidental losses. Historically, much of the operator training in the pulp and paper industry has been based on the operating manuals provided by the suppliers of the equipment. While this can be effective in attaining production levels and meeting product quality specifications, it is less satisfactory with respect to the control of accidental losses, whether environmentally significant or not. Control of these losses requires an appreciation of the overall process system, as well as an understanding of what materials should, or should not, be discharged to sewer, and the procedures to follow in the event of unforseen difficulties.

Personnel training requires a specific training manual and program, prepared by a professionals who have the necessary knowledge of process operation and environmental protection. Separate training is required for shift operators, operating supervisors and maintenance personnel. Some pulp and paper producers have developed this expertise in-house, while others prefer to retain external consulting firms to prepare such manuals and training programs.

14.3 Treatment of Contaminated Condensates

An inherent feature of the kraft pulping process is that toxic contaminated condensates with high BOD are produced in the digester and evaporater areas as shown in Figures 13, 14, 18 and 30. These liquids, also frequently known as foul condensates or occasionally as combined condensates, surface condensor condensates, or turpentine decanter underflow, are often segregated from the mill effluent and treated separately.

14.3.1 Condensate Properties. In kraft pulp mills, contaminated condensates contain 8-15 kg BOD/t pulp. The BOD originates from alcohols, ketones, terpenes, phenolics, resin and fatty acids, and the total reduced sulphur (TRS) compounds. Methanol is the most significant factor in the BOD load.

Reported 96-hour LC_{50} (lethal concentration to 50% of test organisms) values for the toxicity of contaminated condensates range between 0.04% and 17%, using fish as the test organism. Many of the contaminated condensate's components, such as the TRS compounds, and resin and fatty acids, exhibit lethal toxicity at concentrations well below their concentration in contaminated condensates. The TRS compounds appear to be the dominant factor in contaminated condensate toxicity.

Some workers have suggested that the role of TRS compounds in the toxicity of kraft mill effluent is minor, on the supposition that the compounds should be rapidly oxidised or air-stripped in the mill sewer system and in the receiving waters. However, many others have concluded that these condensates contribute 20 to 50% of kraft mill effluent toxicity. The wide variation in data is at least partly due to the difficulty of separating true condensate from black liquor carryover.

Contaminated condensates have been found to taint fist at concentrations in water between 0.2% and 2%. The compounds responsible for the tainting are not definitely known, but phenolics and the TRS compounds are likely major contributors.

The detection threshold is defined as the lowest detectable concentration. Generally this represents the practical lower limits of analytical or instrument technology. In the case of subjective qualities such as taste and odour, it represents judgement by a human test panel. Measured odour detection thresholds of contaminated condensates in water range from 0.5 - 60 ppm. Taste thresholds of contaminated condensates in water range between 50 - 200 ppm. TRS compounds are generally considered to be the main source of water odour and taste.

Contaminated condensates contain about 0.3 kg TRS (as S) per tonne pulp. Since some of the TRS compounds in the condensates are stripped from aerated lagoons by aeration, sewered contaminated condensates can represent a significant source of odour at a biological treatment system. Where sewers containing contaminated condensates are not enclosed, occasional occupational health problems can occur due to high levels of TRS compounds in the workplace air.

Contaminated condensates represent several percent of the total mill effluent volume. Therefore, they can be considered high-strength low-volume wastes that are logical candidates for selective waste treatment.

14.3.2 Condensate Segregation. By properly segregating contaminated condensates, it should be possible to isolate about 3 m^3/t pulp of condensate for selective treatment. This isolated condensate would consist of the digester contaminated condensate and the more contaminated of the multiple-effect evaporator condensates. In the case of a continuous digester the digester contaminated condensate is the flash-steam condensate (often known as turpentine decanter underflow as shown in Figure 13). In the case of a batch digester, the contaminated condensates are the vent and blow condensates as shown in Figure 14. The more contaminated evaporator condensates include the vacuum system condensate or hotwell, the surface condenser condensate, and the condensate from the evaporator bodies on the first, and possibly the second, evaporator effects (as seen by the weak black liquor), where the initial concentration of the liquor occurs. The segregated 3 m^3/t pulp should contain about 90% of the total load of BOD and methanol and about 99% of the TRS load. The typical concentrations of the important components of segregated contaminated condensates are listed in Table 24.

TABLE 24 COMPONENTS OF SEGREGATED CONTAMINATED CONDENSATES

Component	Concentration (mg/L)	Quantity Present (kg/t pulp)
TRS (as S)	100	0.3
Methanol	3000	9.0
Ehtanol	170	0.5
Acetone	130	0.4
Methyl ethyl ketone	50	0.15
Guaiacol	30	0.1
Terpenes	650	3.0

14.3.3 Treatment Processes. Several methods have been developed for selective treatment of contaminated condensates including:

a) stripping with flue-gas, air or steam;
b) carbon adsorption;
c) chemical oxidation with chlorine or oxygen;
d) selective biological oxidation in an aerated lagoon, an activated sludge system or an enclosed trickling filter consisting of bark pieces;
e) spray irrigation; and
f) chemical precipitation.

Stripping is currently the generally accepted method of selective treatment and seems likely to remain so. Stripping systems are usually operated either to remove TRS compounds, or to remove TRS compounds plus methanol.

Generally, removal of TRS compounds alone reduces the toxicity of the contaminated condensates, their potential to cause water taste and odour problems and their fish-tainting propensity. TRS stripping is also practiced to reduce malodourous emissions.

Stripping to remove both TRS compounds and methanol has the additional benefit that the BOD load of the mill is considerably reduced. Also, since phenolics and resin acids may be removed simultaneously, the toxicity and the fish-tainting propensity of the contaminated condensates may be reduced to a greater extent than can be achieved with TRS stripping alone. Essentially two types of condensate stripping systems are used: steam and air.

Conventional steam strippers are really distillation columns, with a stripping section in the bottom, and a rectification or enriching section at the top. Hence, there is an overhead condenser and most of the column overhead is refluxed back to the column as liquid. Stripped material is withdrawn as a small side stream from the overhead condenser, usually as a gas. Impurity concentrations in this side stream are high, typically more than 50% by volume. This material is commonly disposed of by incineration. A typical flowsheet is presented in Figure 39.

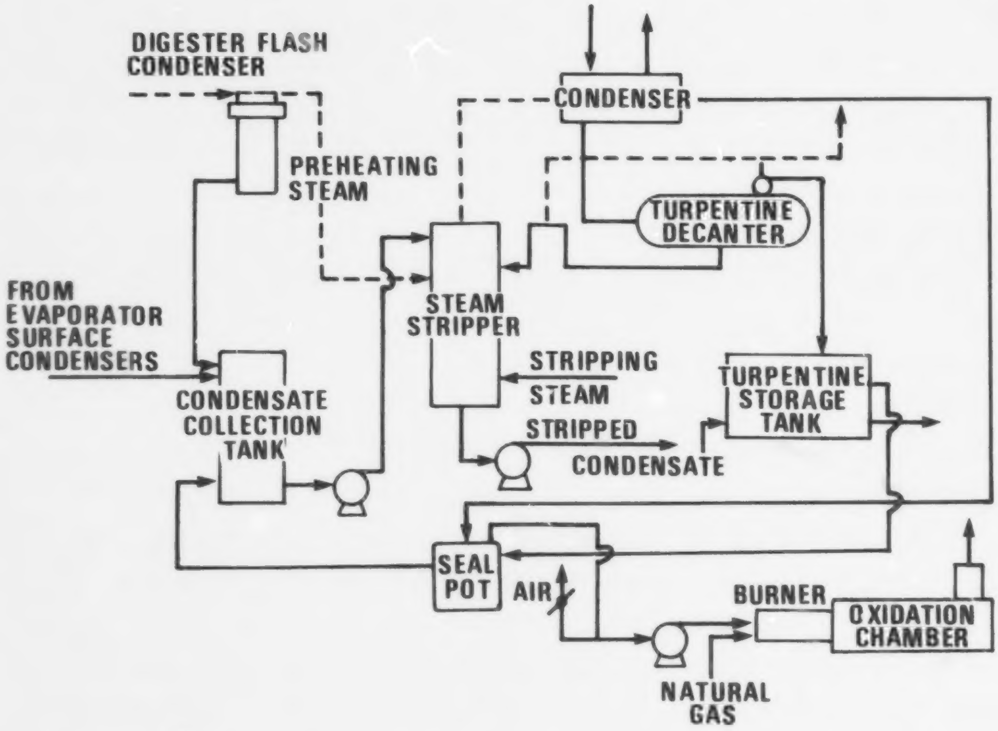
DIGESTER FLASH CONDENSER
PREHEATING STEAM
CONDENSER
TURPENTINE DECANTER
FROM EVAPORATOR SURFACE CONDENSERS
STEAM STRIPPER
STRIPPING STEAM
TURPENTINE STORAGE TANK
CONDENSATE COLLECTION TANK
STRIPPED CONDENSATE
SEAL POT
AIR
BURNER
OXIDATION CHAMBER
NATURAL GAS

FIGURE 39 SCHEMATIC OF STEAM STRIPPING

Steam strippers are usually operated at either five percent applied steam on contaminated condensate or 20% steam. Operation at 5% steam removes TRS, but little

BOD; operation at 20% steam removes almost all of the TRS and BOD. A steam stripper can be designed to operate either with fresh steam, or with suitable process steam such as by integration with the multiple-effect evaporators. For operation with 20% fresh steam, the cost of steam for stripping is typically about $7/ADt, using an incremental steam cost of $12 per 1000 kg, typical for 1983, and assuming a credit for the heat supplied to the stripped condensate and in the overhead condenser cooling water. However, in an energy-efficient mill, much of this hot water may not be required and would therefore be valueless so the actual energy cost can be twice as high. Another factor offsetting the steam cost is the heating value of the stripped gas but this is a relatively minor value in practice.

The installed capital cost of a steam stripping system, including the necessary piping, tankage and instrumentation is typically about $1 500 000. If the stripper is integrated with the evaporators, extra costs are incurred for increasing the size of the evaporators to provide more heat transfer surface. By integrating a steam stripper with the multiple-effect evaporators, the consumption of steam is considerably reduced, but not eliminated because the efficiency of the evaporators is reduced.

While the operating costs for integrated steam stripping are more attractive than those associated with the use of fresh steam, there is still a general reluctance to implement the process. Many existing mills do not have seven or eight percent excess evaporative capacity in their evaporators. At these mills, integrated stripping could not be considered unless the evaporators were expanded. Also, there is some concern about complicating and interferring with the already tricky evaporator operation. A further problem with an integrated stripper is that the stripper can only be operated when the evaporator plant is operating, which may be impractical, since the digesters may operate for up to 24 hours (generating contaminated condensate) while the evaporators are down.

Air strippers are less common than steam strippers, but a number have been installed. They are usually built as packed towers with air flow countercurrent to condensate flow (refer to Figure 40). They can remove up to 98% of the TRS and most of the toxicity from the condensate, but remove only about 30% of the BOD. However, the stripped condensate is generally clean enough for use in dissolving tank vent and lime kiln vent scrubbers where much of the remaining methanol is stripped out, resulting in an overall BOD removal efficiency of around 80% for a well designed system.

In kraft mills seeking compliance with effluent quality regulations without external biological treatment, condensate stripping is usually essential. In most mills with

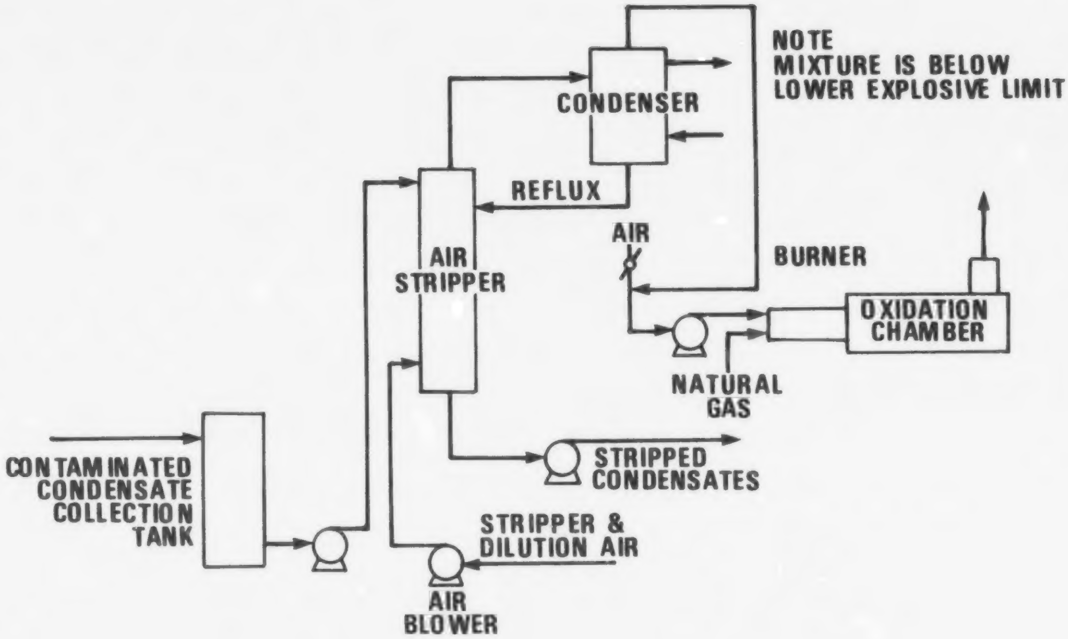
NOTE
MIXTURE IS BELOW
LOWER EXPLOSIVE LIMIT
CONDENSER
REFLUX
AIR
AIR
STRIPPER
BURNER
OXIDATION
CHAMBER
NATURAL
GAS
CONTAMINATED
CONDENSATE
COLLECTION
TANK
STRIPPED
CONDENSATES
STRIPPER &
DILUTION AIR
AIR
BLOWER

FIGURE 40 SCHEMATIC OF AIR STRIPPING

biological treatment, it is usually more cost-effective to treate the condensate in the biological system along with the mill effluent. However, stripping may be required to reduce the odour from the biological treatment system.

In some cases stripping may be more cost-effective than expanding an overloaded effluent treatment system.

14.4 Disposal of Non-Condensable Gases in Kraft Mills

The non-condensable gases are extremely malodorous and are usually the principal contributor to the characteristic kraft mill odour. The term non-condensable gases is applied to the gases emitted from the pulping and black liquor evaporation processes as indicated in Figures 13, 14, 18, 30, and 31. They consist of a mixture of terpenes, total reduced sulphur (TRS) compounds and methanol along with a variety of less significant organics. Strictly speaking, these gases are all condensable, but the above term is universally used to distinguish them from the vapours which do condense in the relief vent, blow heat recovery vent and evaporater non-condensable gas extraction system under normal conditions of operation.

Non-condensable gases are by-products of the kraft cooking process, and although the quantity generated varies with wood species and sulphidity, significant reduction by process modifications is not practicable. TRS is the most environmentally significant component, and most research has centred on the reduction or elimination of TRS, and almost all the available data is quoted in terms of TRS.

Published data on the quantity of TRS generated in the kraft process vary from about 0.2 kg/t pulp to 3 kg/t. The lower values are probably due to experimental error, since much of the early work in the field used analytical techniques now known to be inadequate. The true rate of generation of TRS in kraft mills is probably in the order of 2 kg/t pulp. In any event, the exact quantity is of minor importance, since the regulations that exist all require effectively 100% elimination of these gases from the sources discussed in this sub-section, and the treatment systems are always designed with a large margin on capacity for safety reasons.

Although the total quantity of TRS gas produced per tonne of pulp is relatively constant, the quantities emitted at various points vary widely. With batch digesters, much of the gas is stripped out of the pulp when the digester is blown, and most of the rest exits from the evaporator vent. In the case of continuous digesters, up to about 0.3 kg/t pulp are emitted from the brownstock washer vents, in rather dilute form. If continuous diffusion washers are used, most of the TRS will remain in the black liquor and be emitted from the evaporator vent.

In batch digesters, the non-condensable gases are released along with large quantities of steam. The blow heat recovery system should be sized to condense this steam, but most older systems are inadequately designed. It is impossible to install an effective non-condensable gas collection and incineration system in such cases without first rectifying the inadequacies of the blow heat recovery system, which often requires complete replacement costing in the order of a million dollars.

Some batch digester non-condensable gas incineration systems use a surge tank, often called a "vapoursphere" but these have generally been superceded by design techniques that allow for the variable gas flows inherent in batch systems.

The only proven way of eliminating these gases is by incineration, and this is practiced by a number of mills. The TRS gases, and other non-condensable gases which inevitably accompany them, are explosive when mixed with air, and strict safety measures must be designed into the equipment and observed during operation. The technology is now sufficiently well known to reduce the hazards to a level similar to that of other industrial equipment.

In some cases the non-condensable gases are incinerated in a dedicated incinerator, which is effective but usually requires auxilliary fuel to maintain combustion. Most of the more recent installations incinerate the gases in the lime kiln, the power boiler or the recovery furnace. Any one of these will oxidise the TRS completely to sulphur dioxide, eliminating the odour. The quantity of sulphur dioxide produced is negligible compared with that produced from the combustion of oil or coal.

Scrubbers were used in the past to treat the non-condensable gases. These can be quite efficient in removing hydrogen sulphide, but their efficiency in removing other TRS gases is low (under 50%). They are used frequently in modern installations to recover sulphur for the pulping system and remove terpenes etc. from the non-condensable gases, in the interests of safety, prior to incineration.

14.5 Rapson-Reeve Closed-Cycle Bleached Kraft Mill

In the Section 7, on bleaching kraft pulp, it was pointed out that bleach plant effluent is a major source of kraft mill BOD and toxicity, and that these effluents cannot be recycled within the process if conventional technology is used. To overcome this Drs. Rapson and Reeve developed their concept for a closed-cycle bleached kraft mill and have described it in many publications. Figure 41 illustrates the process concept.

To date, only The Great Lakes Forest Products Co. mill at Thunder Bay, Ontario, has been designed and built to use this process. Since it is the first in the world and has been producing and selling market pulp since start-up in 1977, it must be considered to be successful, although there is still some contaminated effluent discharged and no other mills have adopted the process at the time of writing. The basic features of the process could be implemented in several ways, and an oxygen bleach stage could be incorporated if desired to lower the circulating chloride load. Variations of the kraft contaminated condensate treatment systems described in Section 14.3 could be incorporated into the concept.

The system at Great Lakes can be described as follows:

a) 70% substitution of chlorine dioxide for chlorine in the first bleaching stage,
b) countercurrent washing in the bleach plant,
c) minimal external water input to the bleach plant,
d) use of a salt recovery process to remove sodium chloride from the white liquor,
e) use of the ERCO R-3 or similar process to produce chlorine dioxide,
f) use of a stream stripper to treat evaporator condensates,
f) provision of spill control.

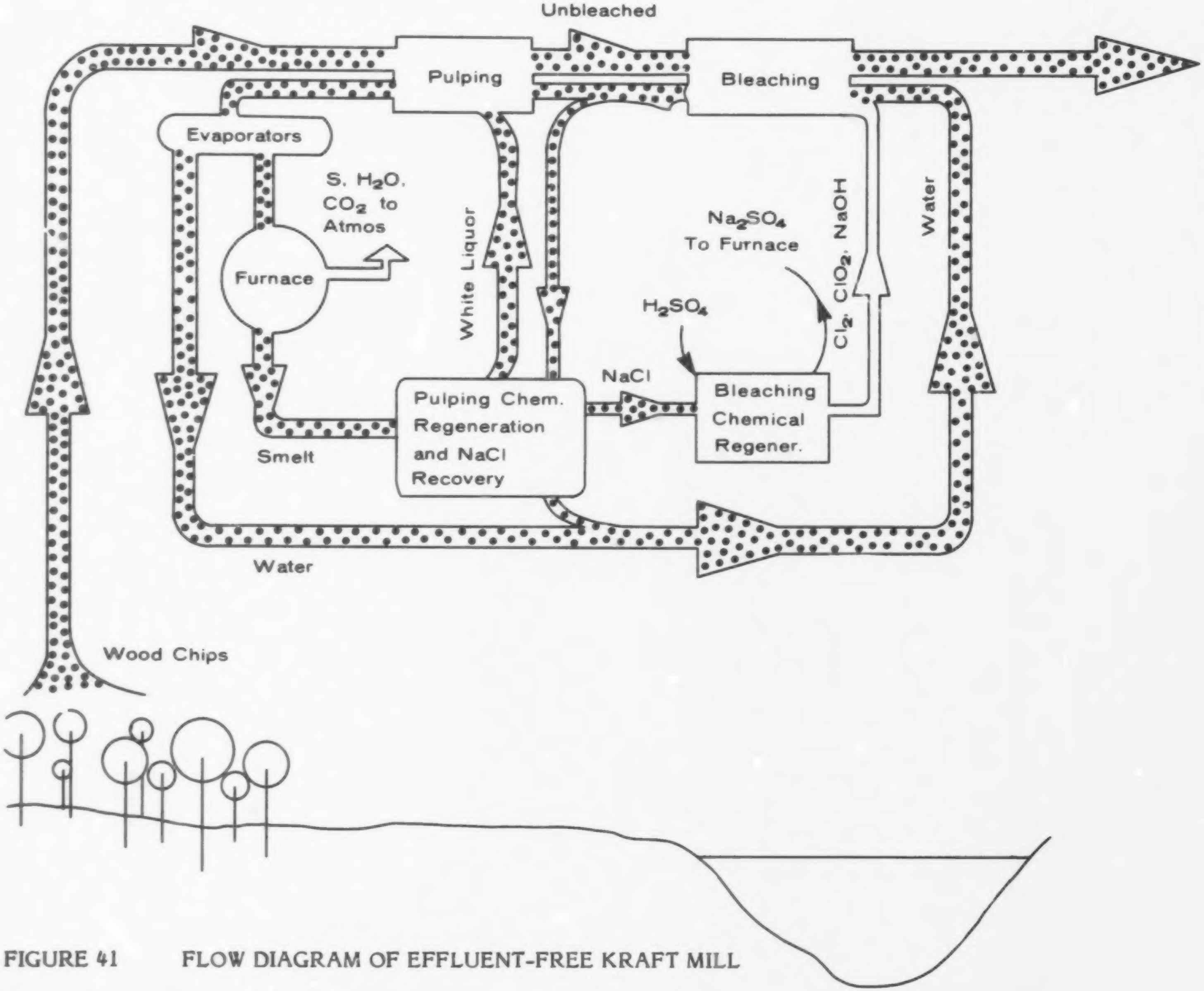
Unbleached
Pulping
Bleaching
Evaporators
S. H_2O, CO_2 to Atmos
Furnace
White Liquor
Na_2SO_4 To Furnace
H_2SO_4
Cl_2, ClO_2, NaOH
Water
NaCl
Pulping Chem. Regeneration and NaCl Recovery
Bleaching Chemical Regener.
Smelt
Water
Wood Chips

FIGURE 41 FLOW DIAGRAM OF EFFLUENT-FREE KRAFT MILL

Substituting chlorine dioxide for chlorine in the first bleaching stage decreases the amount of chloride ion produced in this stage and, therefore, the amount of sodium ion (from sodium hydroxide) required to produce sodium chloride. This results in a much lower input of sodium chloride into the recovery cycle and the salt recovery plant.

Fully countercurrent washing is required in the bleach plant from the second chlorine dioxide stage to the first extraction stage. The showers for the D/C washer are countercurrent from the first extraction stage (applied last to the pulp mat) and from the first chlorine dioxide stage (applied first to the pulp mat). No external wash water is supplied to any of the pulp washers. This means that external water inputs to the bleach plant are also kept to a minimum so that the total spent water volume is low enough to be reclaimed into the recovery cycle. No external water is regularly added to seal tanks except that required for level control. Air doctor pulp takeoffs with low-volume, high-pressure, timer-operated wire cleaning showers are used on the washers rather than hydraulic doctor showers. Second extraction stage filtrate is used to dilute the purchased 50% sodium hydroxide to 13% strength for bleach plant use.

Reclaiming the bleach plant filtrates into the recovery cycle results in introduction of sodium chloride as an inert dead load in the system. The sodium chloride must be removed at the same rate that it is being introduced in order to prevent buildup. The salt recovery process is used for this purpose. The byproduct salt produced is used as sodium chloride supply to the chlorine dioxide generator, and none is sewered.

The ERCO R-3 process produces chlorine dioxide using sodium chlorate, sulphuric acid, and sodium chloride as raw materials. The chlorine dioxide and chlorine are gases and pass to a cold water absorber which dissolves the chlorine dioxide and some chlorine. The off gas from the absorber passes through a caustic scrubber and sodium hypochlorite is produced from the remaining chlorine, The process also produces sodium sulphate, which is removed from the generator by filtration in a separate unit. Some of the sodium sulphate is used as makeup chemical in the kraft recovery cycle, and the remainder is sewered.

A significant portion of the BOD, total reduced sulphur and toxicity of the mill effluent loading is contributed by the black liquor condensates. Because of the tight water cycle within the closed-cycle process, it is not possible to reclaim all of these condensates back into the water cycle. A stream stripper is used to lower the effluent loadings from these condensates.

14.6 Significance of Chemical Oxygen Demand

BOD has long been the most widely used criteria for the definition of wastewater quality in North America. Chemical oxygen demand, commonly known as COD, is used as an alternative measure of the oxygen demand of wastewater, particularly in Eastern Europe.

Some workers have suggested that COD should replace BOD for regulatory and control purposes, usually on the grounds that the analytical procedure is more precise than that used to determine BOD. There is no doubt that COD determinations are more consistent and the procedures are also more adaptable to automated laboratory techniques. Another advantage of the COD analysis is that it can be completed in a few hours, so that the test results can be available on the same day as the effluent sample is collected, whereas the BOD test, by definition, requires five days to complete.

However, the BOD analysis represents a laboratory simulation, however crude, of the reactions which occur when the effluent is discharged to the receiving water, whereas the the conditions in the COD analysis are unrelated to those in any receiving stream.

A number of workers have tried to correlate the BOD of pulp mill effluents with the COD, primarily to provide a more rapid prediction of BOD values than is feasible with the standard BOD analysis. The correlations obtained were not sufficiently close to be useful, even when restricted to specific streams. Generally, it can be said that effluents with high COD also tend to have high BOD, but there is no useful quantitative relationship.

14.7 Alternative Utilization of Spent Sulphite Liquor

Several technological and economic obstacles impede the recovery of chemicals and energy from spent sulphite pulping liquors by processes analogous to the classical kraft recovery process, although substantial quantities of potentially useful chemicals are contained in all types of spent sulphite liquor. This has led to extensive research into alternative uses for these liquors, partly for economic reasons and partly in response to the environmental pressures to reduce BOD discharges.

The few commercially operating systems that use spent sulphite liquor for by-product manufacture are generally based on the low yield pulping processes, since those provide the highest organic chemical content. However, the principal problems with spent sulphite liquor disposal in Canada are in the small, high yield sulphite mills integrated with newsprint mills. The larger market sulphite mills have classic recovery operations and have little need to consider alternative uses of spent sulphite liquor for environmental reasons.

In view of the variety of chemicals present in sulphite waste liquor it is not surprising that there have been many proposals for the manufacture of by-products. Over two thousand patents in the field have been reported in the literature but surprisingly few by-product plants are operating in sulphite mills.

Various potential useful materials have been prepared from spent sulphite liquor but in most cases it would have been necessary to invest substantial sums on the development of markets with the ever-present danger of being undercut by other mills when the business volume reached viable levels, so that very few commercial scale by-product plants have actually been built.

Several plants produce alcohol from the fermentation of sulphite waste liquor but all are low yield mills. It is generally less expensive to manufacture alcohol from other materials than from high yield liquor sulphite waste. The alcohol yield from 75% yield pulping liquor is about one fifth of that from 48% pulping yield liquor. The BOD reduction attainable from alcohol production from high yield liquor is probably under 12 kg/t pulp, so it is hardly significant for environmental protection purposes. The energy balance for alcohol plants in sulphite mills of any yield is usually negative, so there must be a market for alcohol at prices substantially higher than its fuel value for an alcohol plant to be viable.

Vanillin and other by-products are produced by one Canadian mill but market development limits other applications in this case. The principal reductions in effluent BOD and toxicity obtained at that mill are due to the incineration of the waste liquor.

Lignosol chemicals are recovered from low yield calcium base waste liquor by one Canadian mill. The BOD reduction obtained is under 30%, and the process application is limited by the size of the potential market so that widespread use of this process is unlikely.

The Pekilo process for the manufacture of yeast was developed a few years ago in Finland and a full-scale plant is now operating. The extent of BOD reduction attainable is of the same order as for alcohol production.

APPENDIX A
COMMON CHEMICAL SYMBOLS used in the PULP AND PAPER INDUSTRY

CHEMICAL NAMES AND SYMBOLS

Chemical Name	Symbol	Common Name
Aluminum sulphate	$Al_2(SO_4)_3$	Alum
Calcium bi-sulphite	$Ca(HSO_3)_2$	Raw Sulphite cooking acid
Calcium carbonate	$CaCO_3$	Lime rock or lime mud
Calcium chloride	$CaCl_2$	
Calcium hydroxide	$Ca(OH)_2$	Hydrated or slaked lime
Calcium Hypochlorite	$Ca(OCl)_2$	Bleach liquor
Calcium oxide	CaO	Quicklime
Calcium sulphate	$CaSO_4$	
Carbon dioxide	CO_2	
Chlorine	Cl_2	
Chlorine dioxide	ClO_2	
Dimethyl disulphide	$(CH_3)_2S_2$	
Hydrochloric acid	HCl	Muriatic acid
Hydrogen peroxide	H_2O_2	
Hydrogen sulphide	H_2S	
Magnesium sulphate	$MgSO_4$	
Methyl mercaptan	CH_3SH	
Oxygen	O_2	
Ozone	O_3	
Sodium bicarbonate	$NaHCO_3$	Baking soda
Sodium carbonate	Na_2CO_3	Soda Ash
Sodium chlorate	$NaClO_3$	
Sodium hydrosulphite	$Na_2S_2O_4$	
Sodium hydroxide	$NaOH$	Caustic soda
Sodium sulphate	Na_2SO_4	Salt cake
Sodium sulphide	Na_2S	
Sodium Thiosulphate	$Na_2S_2O_3$	
Sulphur dioxide	SO_2	
Sulphur trioxide	SO_3	

Sulphuric acid	H_2SO_4
Titanium dioxide	TiO_2
Water	H_2O
Zinc hydrosulphite	ZnS_2O_4

APPENDIX B

BIBLIOGRAPHY

APPENDIX B BIBLIOGRAPHY

The following textbooks provide much more detailed descriptions of the pulp and paper industry production processes and equipment than is possible in this manual, and are recommended to readers who require further information.

Gary A. Smook, Handbook of Pulp and Paper Technology, CPPA, January 1983 (This is probably the best follow-up reading for most readers of this manual. It describes all production equipment in detail.)

J.P. Casey, Pulping and Paper Chemistry and Technology, Volumes I, II, and III, Wiley Interscience, 1981. (This is probably more detailed than readers of this manual would desire but is the most recent fully comprehensive manual which treats process theory.)

R.P. Singh (Editor), The Bleaching of Pulp, TAPPI Press, 1979

R.G. MacDonald (Editor), Pulp and Paper Manufacture, Volumes I,II, and III, CPPA, 1970, (Review of technology and equipment in pulp and paper industry written by a number of expert authors. Now somewhat dated. A 12-volume revised edition is scheduled for publication in 1984.)

Pulping Processes, S.A. Rydholm, Interscience Publishers, 1965 (Still a classic on fundamental processes.)

C.W. Conaway, BLRBAC Report on Safe Firing of Black Liquor, Industrial Risk Insurers, Hartford, Connecticut, The Black Liquor Recovery Boiler Advisory Committee, 1982.

K. Britt, (editor), Handbook of Pulp and Paper Technology, 2nd edition, Van Nostrand Reinhold Company, 1970.

H.F. Wenzl, Kraft Pulping Theory and Practice, Lockwood Publishing Co., 1967.

Chemical Recovery in Alkaline Pulping Processes, TAPPI Monograph No. 32, 1968.

W.E. Hillis, Wood Extractives and Their Significance to the Pulp and Paper Industry, Academic Press, 1962.

Groundwood Operating Manual, CPPA, 1967.

Sulphite Operating Manual, CPPA, 1976.

CPPA publications are available from:

Publications Secretary
Technical Section, CPPA,
Sun Life Building, 23rd Floor,
1155 Metcalfe Street,
Montreal, Quebec H3B 2X9

The following Environment Canada Reports were consulted (and in some cases passages were extracted):

Air Pollution Emissions and Control Technology: Wood Pulping Industry, EPS 3-AP-77-6, Air Pollution Control Directorate, 1979.

The Basic Technology of the Pulp and Paper Industry and its Waste Reduction Practices, EPS 6-WP-74-3, Water Pollution Control Directorate, 1974.

Mill-Scale Application of the Rapson-Reeve Closed-Cycle Process at Great Lakes Products Limited, EPS 4-WP-80-4, Water Pollution Control Directorate, 1980.

Proceedings of Seminars on Water Pollution Abatement Technology in the Pulp and Paper Industry, EPS 3-WP-76-4, Water Pollution Control Dictorate, 1976.

Stripping Kraft Foul Condensates with Waste Gases, EPS 3-WP-82-1, Water Pollution Control Directorate, 1982.

Contaminated Condensate Treatment by Stripping, Envirocon Ltd. CPAR Report 898-1, CPAR Secretariat, Environmental Protection Service, 1979.

Guidelines for the Pulp and Paper Effluent Regulations, EPS 1-WP-72-2, Water Pollution Control Directorate, May, 1972.

Standard Procedure for Testing the Acute Lethality of Liquid Effluents, EPS 1-WP-80-1, Water Pollution Control Directorate, May, 1982.

The Control of Air Pollutant Emissions from a Kraft Recovery Boiler using an Alkaline-Carbon Scrubbing System, DSS Contract No 05576-00088, Environment Canada, March, 1981.

The BOD and Toxicity of Effluents from Sulphite Pulping for Newsprint, EPS 4-WP-75-3, Water Pollution Control Directorate, November, 1975.

Toxicity of Effluents from Sulphite Pulping Operations Practicing Recovery and Biological Treatment, EPS 3-WP-79-9, Water Pollution Control Directorate, October, 1979.

Technology and Associated Cost for Sulphite Pulping Spent Liquor Recovery, EPS 3-WP-77-8, Water Pollution Control Directorate, June, 1977.

Estimate of Costs for Water Pollution Control Measures in the Pulp and Paper Industry, EPS 3-WP-77-11, Water Pollution Control Directorate, September, 1977.

Secondary Fibres Pulping/Deinking Effluents Toxicity Study, EPS 3-WP-79-6, Water Pollution Control Directorate, October, 1979.

Technical, Economic and Environmental Aspects of Wet and Dry Debarking, EPS 3-WP-78-3, Water Pollution Control Directorate, March 1978.

Pulp and Paper Effluent Regulations, EPS 1-WP-72-1, Water Pollution Control Directorate, November, 1971.

Over 5 000 articles have been published in pulp and paper industry technical journals in the last 10 years concerning pollution and the environment. Readers with specific need should consult them, preferably via one of the commercial computer data banks such as DIALOG, or INFOMART.

PULP AND PAPER RESEARCH INSTITUTE OF CANADA (Pointe Claire, Quebec) performs literature searches for a nominal fee.

The National Research Council's CAN-OLE literature service has quite complete coverage of Canadian sources, including government publications, but does not include the Abstracts Bulletin of the Institute of Paper Chemistry (ABIPC) which is the best source for most pulp and paper industry oriented searches. The other services mentioned above include ABIPC under the trade name PAPERCHEM.

APPENDIX C

WOOD CHEMISTRY

APPENDIX C WOOD CHEMISTRY

Tree Structure

A tree can be considered to have three general parts:

1) the crown, composed of leaves and branches,
2) the stem, and
3) the root system.

The leaves or needles are the factories where the food material is manufactured to provide energy and growth of the tree through photosynthesis (the production of carbohydrates from carbon dioxide and water in the presence of chlorophyll and light).

Figure C-1 is a cutaway sketch of a tree trunk showing its general structure. The cambium is a thin layer of cells between the bark and the sapwood, where cell growth takes place. The rate of growth varies with the seasons giving rise to the deposition of thin wall fibre cells in the spring and the more dense thick wall fibres in the fall. The cambium is dormant during the cooler months of the year. This yearly growth is responsible for the annual rings phenomenon, the total number of which represent the tree's age.

The inner bark is a narrow layer containing conducting and storage cells. The outer bark is a collection of dead cells which originally existed in the inner living bark. Chemically it is composed of a variety of extraneous components in addition to cellulose, hemicellulose, and lignin.

The sapwood portion of the tree provides structural support for the tree crown, acts as a food storage reservoir and provides the important function of sap conduction. It is physiologically active and in continuous communication with the cambium and inner living bark.

The interior heartwood is a core of dead wood cells in the centre of the stem whose physiological activity has ceased. It functions only as mechanical support. Heartwood is usually much darker in colour than the sapwood, due to the deposition of resinous organic compounds in the cell walls and cavities. Such deposition makes liquor penetration in the pulping process more difficult in heartwood than in the sapwood.

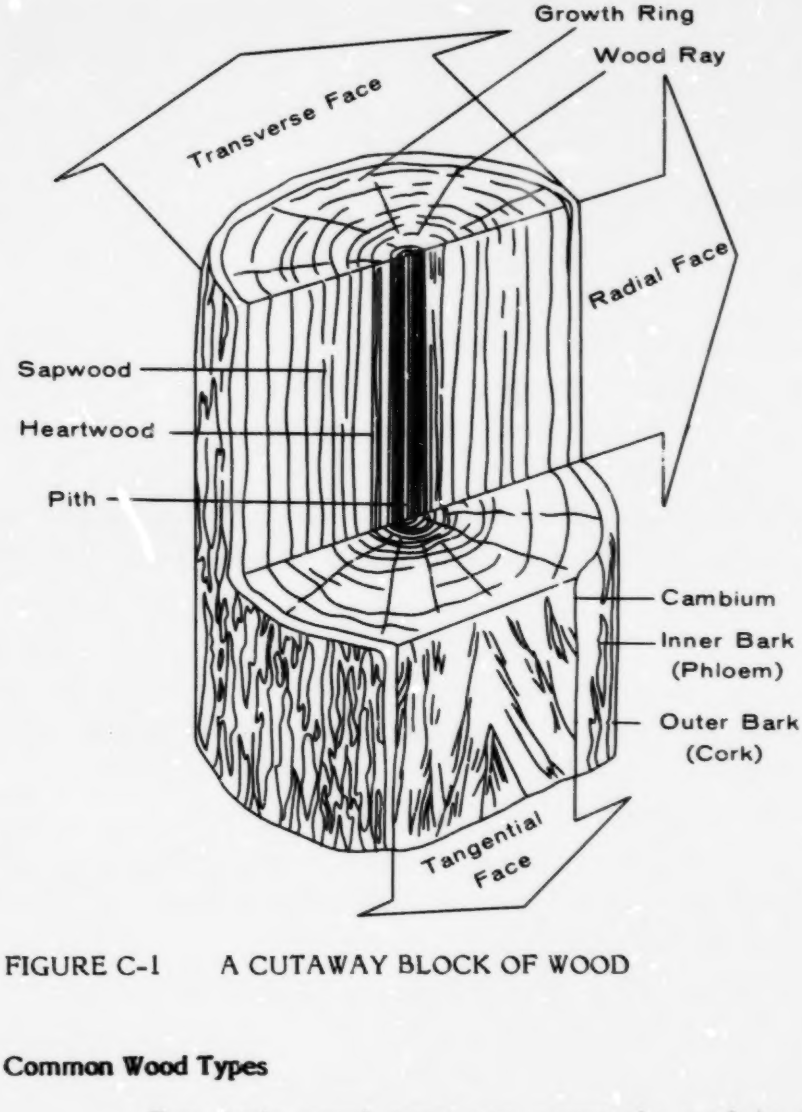
Growth Ring
Wood Ray
Transverse Face
Radial Face
Sapwood
Heartwood
Pith
Cambium
Inner Bark
(Phloem)
Outer Bark
(Cork)
Tangential
Face

FIGURE C-1 A CUTAWAY BLOCK OF WOOD

Common Wood Types

Two basic wood types are commonly used in Canadian pulp and paper manufacture. These are the Conifers (gymnosperms) or softwood species and the Hardwoods (angiosperms) or broadleaf species.

The conifers predominate and represent about 80% of available forests in Canada. The most important species are jack pine, spruce, fir and hemlock. They usually occur in quite pure stands and are most suitable for conventional pulping processes. The important structural element of conifers from the papermaking viewpoint is the tubular-like fibre of conifers in Figure C-2. The early wood tracheid has considerable more pitting than the late wood tracheid. This is, of course, due to the greater degree of physiological activity taking place when the early wood cell was formed.

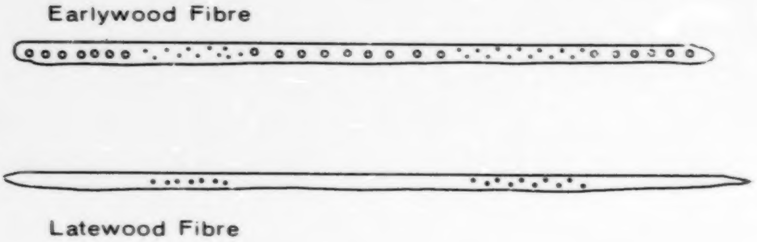

FIGURE C-2 EARLY WOOD AND LATE WOOD TRACHEIDS

The hardwood species represent those trees which lose their leaves annually. The most common Canadian species used for pulping are birch, aspen, poplar, and maple. Hardwoods have a denser structure than softwoods and are more difficult to pulp. Their extractive content in terms of colour and resin components is also higher than in softwoods. The major anatomical difference in hardwoods, compared to conifers, is the presence of vessel elements. Individual vessels are short in length but in the tree they link up to form pipeline-like systems whose major function is the conduction of sap. The fibres in hardwoods range in length between 1 - 2 mm and have very little fibre wall pitting compared to softwood fibres. Examples of typical hardwood fibres and vessels are illustrated in Figure C-3.

Fibre Structure

A cross-section view of a typical fibre cell is illustrated in Figure C-4. All fibres are tubular in nature possessing inner cavities referred to as the fibre leumen. The cell wall structure of a fibre can be seen to be composed of an outer primary wall and an inner secondary wall divided into three layers: the outer (S1); middle (S2) and; inner (S3) layers. The reason for differentiating the secondary wall layers lies in the different orientation of the cellulose fibrils making up its structure. The intercellular substance shown is a resinous adhesive whose function is to bond the cells together providing strucural rigidity to the tree. This substance is called lignin. In softwoods it is present to the extent of 26 to 30% by weight while in hardwoods it varies from 18 to 25%. In order to free individual fibres from each other for papermaking purposes the lignin must be

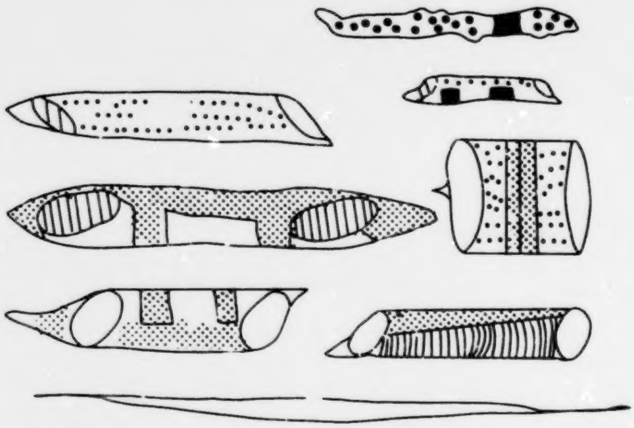

FIGURE C-3 TYPICAL HARDWOOD FIBRES AND VESSEL ELEMENTS

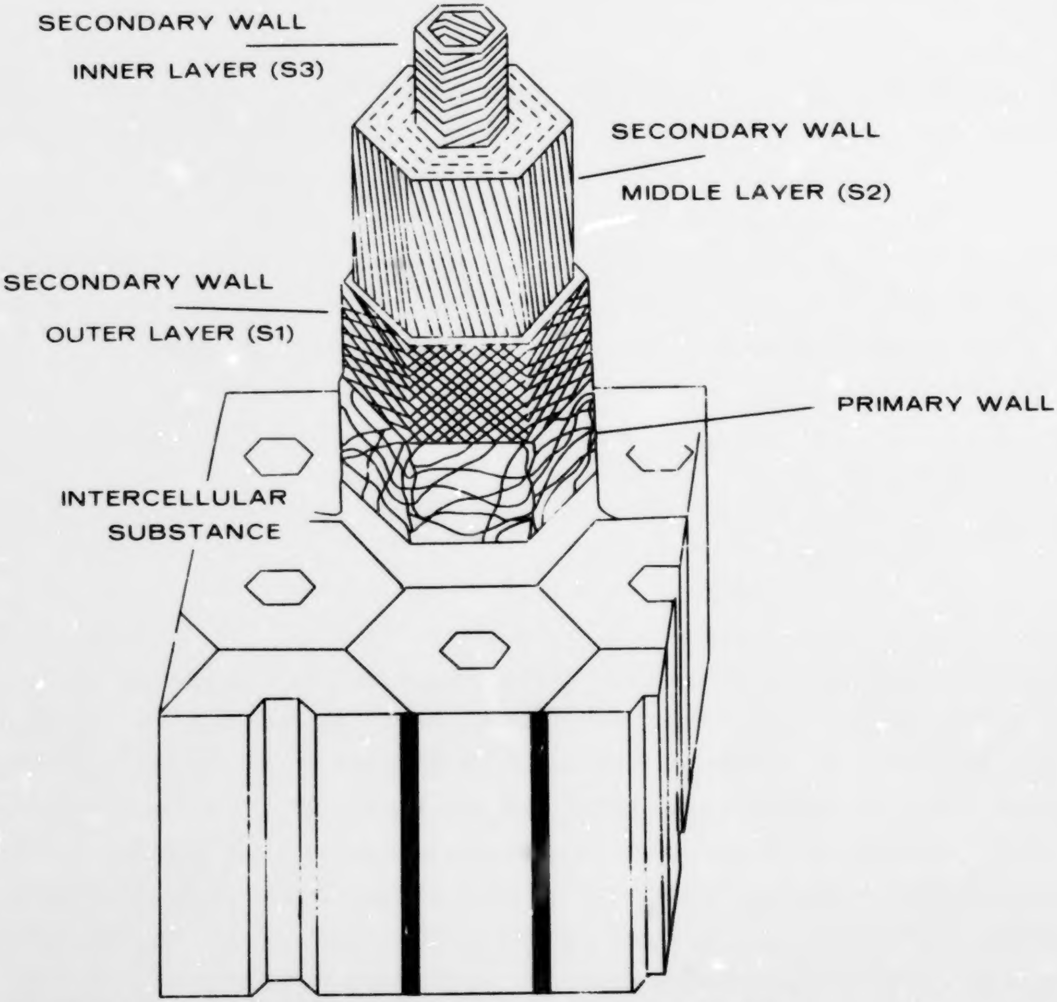
SECONDARY WALL
INNER LAYER (S3)
SECONDARY WALL
MIDDLE LAYER (S2)
SECONDARY WALL
OUTER LAYER (S1)
PRIMARY WALL
INTERCELLULAR
SUBSTANCE

FIGURE C-4 SCHEMATIC STRUCTURE OF A WOOD FIBRE removed. The degree to which the lignin is removed depends on the extent and type of mechanical and chemical energy applied to the wood in the pulping operation.

Importance of Fibre Morphology in Pulping

The anatomical structure of the wood is most important in chemical pulping because it largely controls the extent and manner to which the pulping chemicals penetrate and diffuse through the wood. While chipping the log exposes greater wood surface, it is the capillary network and pitting between fibres and other wood cells that mainly control liquor penetration.

In softwoods liquor penetration occurs mainly through the lumen of the tracheid fibre and their many connecting border pits and capillaries. In hardwoods penetration occurs rapidly through the large lumens of vessel segments but delignification is slower than for softwoods because of the lack of fibre wall pitting. Fibre wall pitting aids in the diffusion of the chemicals into the highly lignified middle lamella. Diffusion of the chemicals through the fibre wall to the middle lamella also occurs but at a slower rate. Once the chemicals have reached the middle lamella delignification occurs by the dissolving of lignin network into soluble forms of varying size.

Importance of Fibre Morphology in Papermaking

Two of the important physical properties of paper are the tensile and burst strengths. While a detailed analysis of this topic is inappropriate to the aim of this manual, it should be recognized that the anatomical features of:

1. fibre length and width,
2. cell wall thickness,
3. basic density (ratio of cell wall thickness to diameter is a good index of fibre density),
4. percentage of springwood and summerwood, and
5. lumen diameter.

all have a direct bearing on the strength quantities of the paper. While chemical composition of fibres also play a role in the determination of strength properties they are not as important as the anatomical features. Springwood fibres for example, with their thin cell walls and large lumen, collapse readily on pulping giving large surface areas for fibre to fibre bonding.

This high degree of fibre bonding produces paper with:

1. high tensile and burst strength,
2. low bulk,
3. smooth surface for printing, and
4. low tear resistance.

Summerwood fibres, on the other hand, possessing thick cell walls and small lumens produce paper with:

1. high tear resistance,
2. high bulk, and
3. low tensile, burst and fold.

These fibres do not collapse readily on pulping, remain rigid, and thus do not provide strong fibre-to-fibre bonding.

The Chemical Elements in Wood

The elemental composition of both hardwoods and softwoods is quite similar and approximates that shown in Table C-1 and Figure C-5.

TABLE C-1 THE CHEMICAL ELEMENTS IN WOOD

Element	% by W. (approx.)
Carbon	50%
Oxygen	44%
Hydrogen	6%
Nitrogen	0.1%
Ash (inorganic)	0.3%

The actual constituent composition of wood is usually broken down into three major chemical systems:

1. polysaccharides,
2. lignins, and
3. extractive substances.

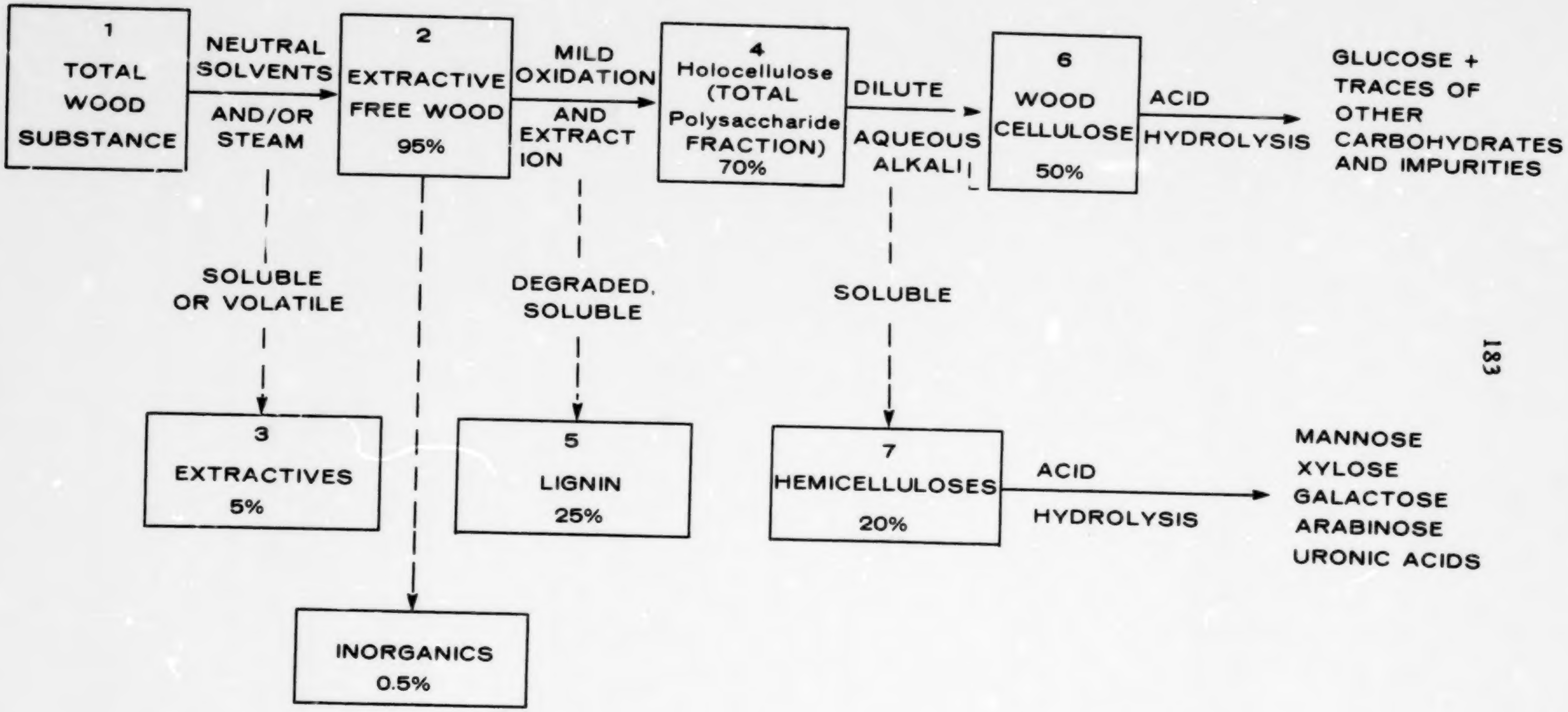
1
TOTAL
WOOD
SUBSTANCE
NEUTRAL
SOLVENTS
AND/OR
STEAM
2
EXTRACTIVE
FREE WOOD
95%
MILD
OXIDATION
AND
EXTRACTION
4
Holocellulose
(TOTAL
Polysaccharide
FRACTION)
70%
DILUTE
AQUEOUS
ALKALI
6
WOOD
CELLULOSE
50%
ACID
HYDROLYSIS
GLUCOSE +
TRACES OF
OTHER
CARBOHYDRATES
AND IMPURITIES
SOLUBLE
OR VOLATILE
3
EXTRACTIVES
5%
DEGRADED,
SOLUBLE
5
LIGNIN
25%
SOLUBLE
7
HEMICELLULOSES
20%
ACID
HYDROLYSIS
MANNOSE
XYLOSE
GALACTOSE
ARABINOSE
URONIC ACIDS
INORGANICS
0.5%

FIGURE C-5 THE CHEMICAL COMPONENTS OF WOOD

When wood is ground and extracted with neutral solvents such as water, alcohol, benzene, ether, and acetone as much as 3 - 10% of the wood will dissolve. This extractive fraction is responsible for the colouring in pulp mill effluents. The alcohols flash off and represent an atmospheric contaminant. Emphasis has been given to these substances in discussions of by-product stream contaminants.

The polysaccharide portion of wood is found in the fibre cell wall. Depending on the wood species it comprises between 60 - 80% of the total dry wood weight. Wood polysaccharides are simply high molecular weight carbohydrates composed of simple sugars such as glucose mannose, and xylose. The polysaccharide fraction is comprised of cellulose and hemicellulose. Together they are generally referred to as holocellulose. The major polysaccharide component of wood is cellulose. It is a polymer of the simple sugar glucose and depending on its D.P. or Degree of Polymerization (i.e., number of glucose units in the polymer) can have very high molecular weight. The D.P. of cellulose generally ranges from 1 000 to 15 000. Cellulose in the fibre cell wall has both amorphous and crystline characteristics. A schematic breakdown of cellulose to its simplest form is illustrated in Figure C-6.

The other lower molecular weight polysaccharides are referred to as the hemicelluloses. Because of their branching they are more complex polymers than cellulose. Their structure consists of a varying combination of mannose, xylose, galactose, and arabinose units together with uronic acid units. The hemicellulose fractions that contain xylose are often termed xylans or pentosans because xylose is the most common pentose sugar. Another type of hemicellulose consists largely of mannose units liked to each other and to glucose units. These are the glucomannans. Examples of their chemical structure is shown in Figures C-7 and C-8. Table C-2 below gives an indication of the relative quantities of the hemicelluloses in hardwoods and softwoods. The hemicelluloses are less resistant to degradation than cellulose during chemical pulping and as a result the degraded products end up in the spent liquors adding to the BOD loading.

Lignin is the second most abundant component of wood, accounting for 25 - 30% by weight. The lignin network is concentrated between the fibre cells. It cements the fibres together giving the tree structural rigidity. Lignin is formed in the wood after the carbohydrates have been laid down. Lignification actually begins when the secondary wall of the fibre is being formed. The basic building block of lignin is the phenyl-proprane monomer shown in Figure C-9.

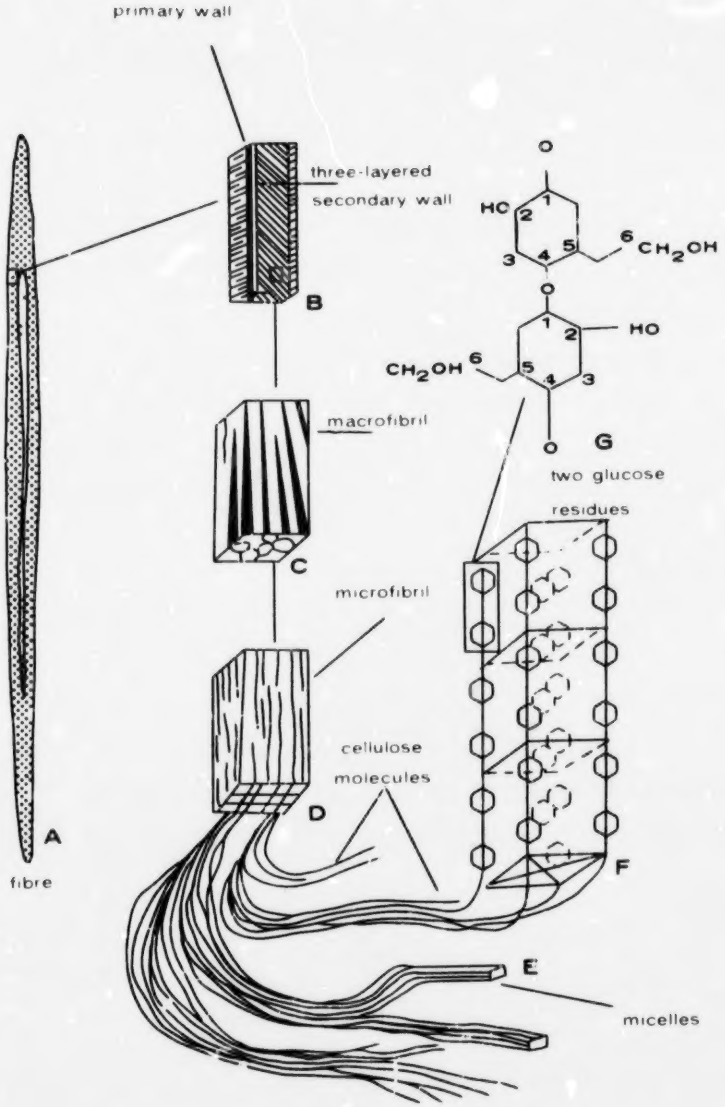
primary wall
three-layered
secondary wall
B
macrofibril
C
microfibril
D
cellulose
molecules
A
fibre
E
micelles
F
G
two glucose
residues
O
HO
1
2
3
4
5
6
CH2OH
HO
CH2OH
O

FIGURE C-6 MICROSCOPIC AND SUBMICROSCOPIC STRUCTURE OF CELLULOSE

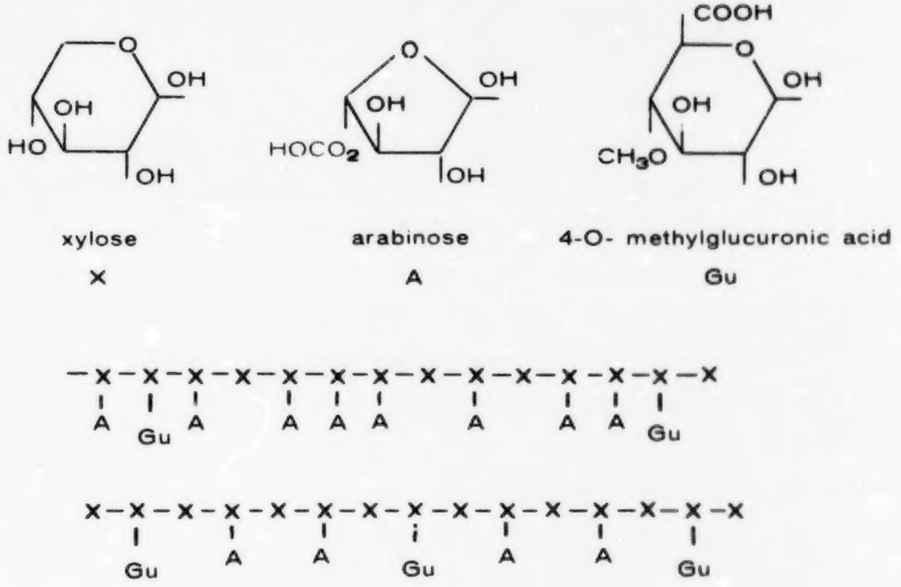
COOH
OH
HOCO2
CH3O
xylose
X
arabinose
A
4-O- methylglucuronic acid
Gu

FIGURE C-7 STRUCTURE OF XYLANS

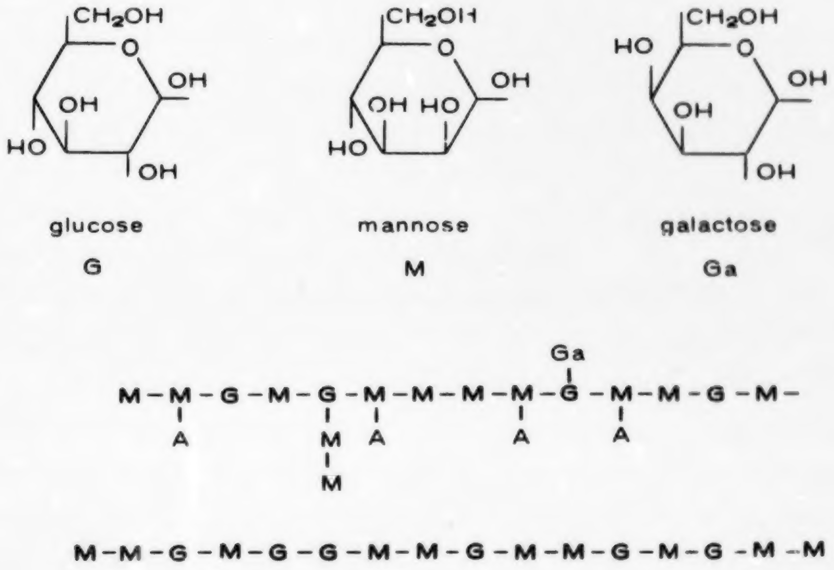
CH2OH
OH
HO
glucose
G
mannose
M
galactose
Ga

FIGURE C-8 STRUCTURE OF GLUCOMANNANS

TABLE C-2 MAJOR CARBOHYDRATE POLYMER COMPONENTS OF HARDWOOD AND SOFTWOOD HEMICELLULOSES

Polymer	Relative Amount Present Softwoods	Hardwoods
4-0-Methylglucuronoxylan (acetate)	small/none	very large
4-0-Methylgluycuronoarabinoxylan	medium	trace
Glucomannan	nil	small
Galactoglucomannan (acetate)	very large	nil
Arabinogalactan	large for larch	nil

Lignin itself is a complex three dimensional-network of phenyl-propane units held by ether and carbon bonds as exemplified in Figure C-10. Its structure is still not completely understood. Lignin is usually considered a polymer of infinite molecular weight and for this reason it is insoluble in any solvent until it is degraded.

Mechanisms of Pulping

The solubility of lignin is chiefly controlled by:

1. the interaction of sulphur compounds with the lignin through Sulphonation in the sulphite process and sulphidation in the kraft process; and
2. the rate of hydrolysis which is largely governed by pH adjustment. (Hydrolysis refers to the cleavage of lignin-lignin or lignin- carbohydrate linkages and the introduction of hydroxyl groups where the split occurs.)

Examples of sulphonation, sulphidation and hydrolysis are given in Figures C-11, C-12, and C-13.

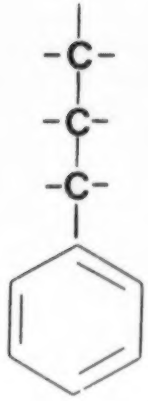

FIGURE C-9 PHENYL-PROPANE MONOMER

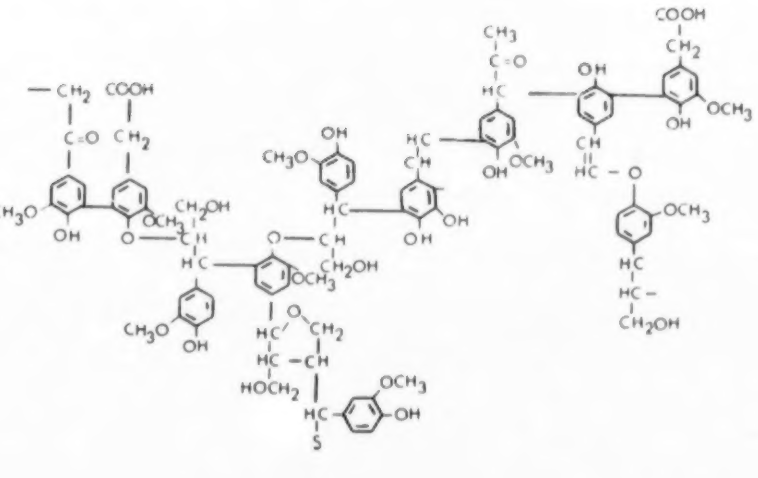
CH2
COOH
C=O
CH2
CH3O
OH
OCH3
CH2OH
O
CH
HC
CH3O
OH
O
CH
CH2OH
OCH3
HC
CH
OH
CH3
C=O
HC
OCH3
COOH
CH2
OH
OCH3
CH
HC
O
OCH3
HC
HC
CH2OH
O
CH2
HC
CH
HOCH2
HC
S
OCH3
OH

FIGURE C-10 TENTATIVE STRUCTURAL FEATURES IN A SEGMENT OF PINE KRAFT LIGNIN MOLECULE

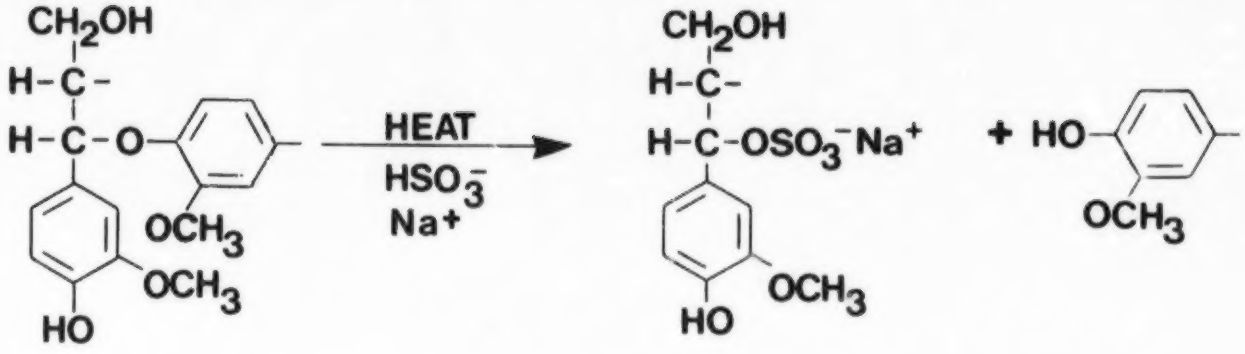
CH2OH
H-C-
H-C-O
OCH3
OCH3
HO
HEAT
HSO3−
Na+
CH2OH
H-C-
H-C-OSO3−Na+
OCH3
HO
+ HO
OCH3

FIGURE C-11 SULPHONATION REACTION OF LIGNIN

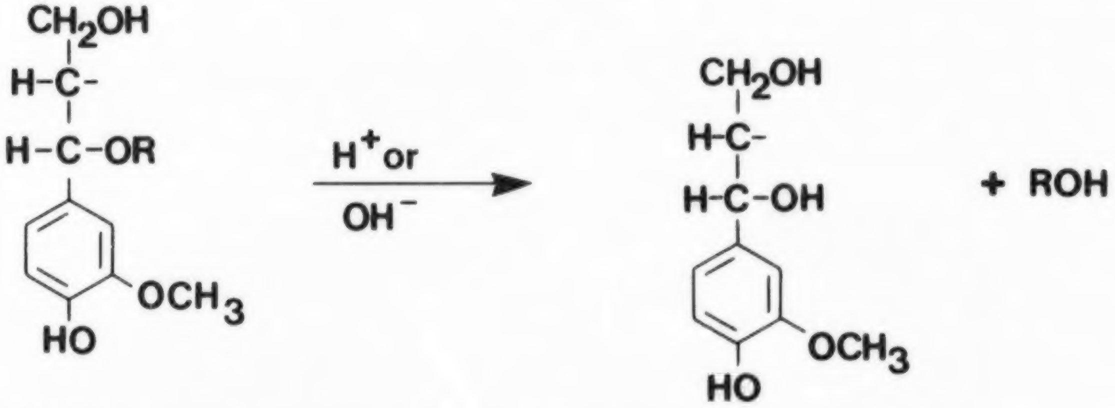
CH2OH
H-C-
H-C-OR
OCH3
HO
H+or
OH−
CH2OH
H-C-
H-C-OH
OCH3
HO
+ ROH

FIGURE C-12 ACID OR ALKALINE HYDROLYSIS

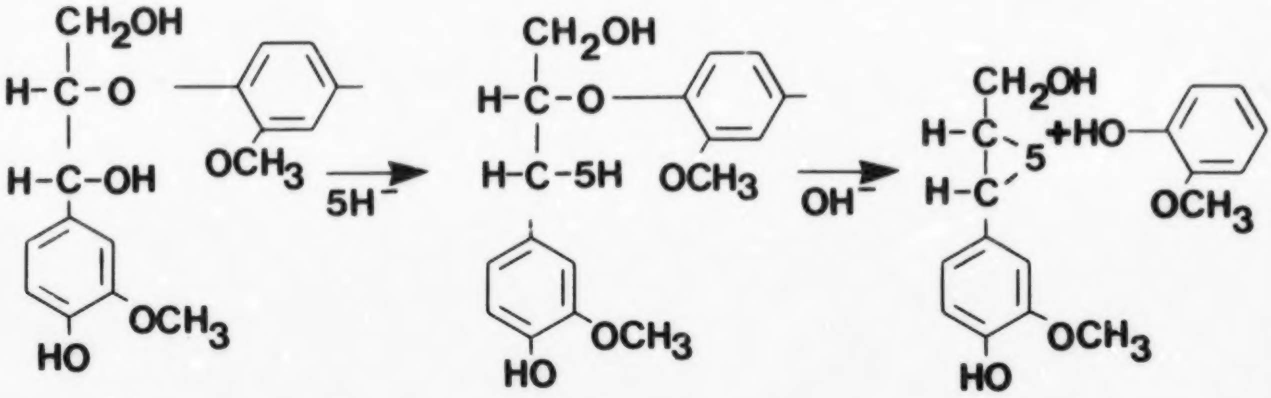
CH2OH
H-C-O
H-C-OH
OCH3
OCH3
HO
5H−
CH2OH
H-C-O
H-C-5H
OCH3
OCH3
HO
OH−
CH2OH
H-C
5
H-C
+HO
OCH3
OCH3
HO

FIGURE C-13 SULPHIDATION AND ALKALINE HYDROLYSIS OF LIGNIN

APPENDIX D

GLOSSARY OF PULP AND PAPER TERMS
(Including abbreviations used in this manual)

APPENDIX D GLOSSARY OF PULP AND PAPER TERMS

Additives	Non-fibrous raw material used in paper making.
Air Dry	The term "Air Dry" signifies 90% dry fibre and 10% moisture (1 ADt = 900 kg OD pulp).
Air Knife	The air knife acts on a principle of a doctor blade and uses a thin jet of air for removing the excess coating from a wet, freshly coated sheet.
Basis Weight	Formerly the weight in pounds of a standard ream of paper. (This unit is far from standardised in the English System.) The SI unit is g/m^2, often called grammage.
Bauer McNett	The method for classification of pulp and paper fibres by passing a sample through a series of standard screens with different size holes and determining the percentage return in each screen.
Beater	A machine used to mix, blend, defibre or refine pulps.
Black Liquor	A liquid in the kraft process composed of spent pulping chemicals and wood residues. Weak black liquor refers to concentrations under 20% solids, strong black liquor to concentrations over 50% solids.
Blanket (offset blanket)	A smooth sheet of rubber backed by fabric used in offset printing to carry the image from the plate to the paper.
Blow Tank	A tank which receives the pulp discharged (blown) from the digester in a chemical pulp mill.
Blow Pit	A sump or chest with the same function as a blow tank.
Bone dry (BD)	See oven dry.
BOD	Biochemical oxygen demand is a property of effluent wastewater determined by measuring the quantity of oxygen consumed by a sample under controlled conditions (20°C, neutral pH) for a defined time period. Often written as BOD_5 where the subscript refers to the length of the test in days. The most commonly used period is 5 days which should strictly be written as BOD_5. However, the use of "BOD" for the 5-day test is common in North America and has been adopted throughout this manual.
Breaker Stack	A vertical press located between dryer sections, where the sheet is still partially wet. It compacts the sheet and improves surface smoothness.

Breaking Length	The length of a sheet of paper which would break of its own weight when suspended vertically.
Breast Roll	The roll which carries the paper machine wire at the forward end of the Fourdrinier table where the stock is spread onto the wire.
Brightening	A term commonly used to describe limited bleaching of mechanical pulp. Refer also to Section 7.
Brightness	A measure of the whitness of paper as compared to a standard. Refer also to discussion in Section 7
Broke	Paper that has been discarded anywhere in the process of manufacture. It is usually returned to a repulping unit for reprocessing.
Brown Stock	Kraft slush pulp prior to bleaching.
Bulk Index	An expression obtained by dividing caliper by the basis weight. It is effectively the specific volume. In SI units it is cm^3/g.
Burr	A tool for surfacing pulpstones. The usual types are thread burr, straight burr and diamond point burr.
Calender	Part of a paper machine consisting of a stack of chilled iron rolls to control caliper and surface smoothness of the web of paper as it passes between the nips of the rolls.
Caliper	The thickness of a sheet of paper measured in thousandths of an inch in the English system and microns in the SI system.
Caustic	Commonly used name for sodium hydroxide.
Caustic Extraction	Bleaching stage where highly coloured organics are dissolved with alkali normally NaOH.
Causticiser	A tank used to allow calcium hydroxide and sodium carbonate to react and form sodium hydroxide and calcium carbonate.
Chop	A short, chunky bundle of unseparated fibres that occurs in groundwood; short shives.
CMD	See machine direction
Coating	The layer of adhesive and/or pigment substances which have been applied to the surface of paper or paperboard to create a new surface.

Coating Weight	The amount of dry coating; usually expressed as pounds per ream or g/m^2.
COD	Chemical Oxygen Demand
Combined SO_2	Sulphur dioxide gas that has become combined with an alkaline base.
Condensate	Water condensed from steam which has come into contact with a surface at a lower temperature during a process. Contaminated or foul condensate usually refers to the condensed vapour from evaporation of black liquor or other spent pulping liquor.
Coniferous Trees	Cone-bearing and evergreen trees, such as spruce, hemlock, Douglas fir, pine.
Consistency	Weight per cent of moisture free, or air dry (as specified) fibres in a suspension of pulp fibres in water.
Cook	Normal term for the chemical pulping process in the digester where the fibre is separated from lignin by chemicals under pressure, at elevated temperatures as described in the pulping process section of the manual.
Couch Roll	The final roll or rolls dewatering the sheet just before it leaves the wire section and enters the press section of a paper machine. The bottom couch roll, or the more commonly used suction couch roll, is employed to drive the machine wire.
Crown	A roll is said to be crowned when it is larger in diameter in the middle than at the ends and gradually tapers from the middle to the ends to compensate for deflection.
Crushing	A defect in paper caused by excessive nip pressure while in too moist a state.
Cubic Unit	A 200 cubic foot bulk volume measurement for wood chips, sawdust or hog fuel. SI system uses m^3.
Curl	Malformation in sheets of paper due to two-sidedness in the sheet, leading to unequal shrinkage between the wire and felt side when subjected to changes in relative humidity.
Dandy Roll	A skeleton cylinder covered with woven wire cloth, placed at the top of the Fourdrinier wire at the suction box area to improve formation and compact the wet sheet. Also used to apply watermark.

Decanter (turpentine)	A tank used to separate turpentine from condensate.
Deciduous Trees	Hardwoods or broadleaf trees which lose their leaves in winter, such as alder, maple, oak, birch and cottonwood.
Decker	An apparatus for dewatering pulp by filtering the fibres out on a mesh covered drum. It generally consists of a vat, a cylinder mold and a couch roll from which stock is removed by a doctor.
Densometer	An instrument to measure the resistance of paper to the passage of air.
Dilution Factor (DF)	See Section 5.3.3
Direct Dyes	A class of aniline dyes, also called substantive dyes, so-names because of their high affinity for cellulose.
Direct Contact Evaporators	Refer to Section 11.1
Disc Refiner	A continuous refiner, in which refining is accomplished by passing the stock between grooved plates located on two discs moving one relative to the other. This is the predominant type of refiner today. Usually one disc is stationary while the other is rotating.
Dispersant (dispersing agent)	A surface-active material added to a suspending medium to promote and maintain separation of individual, fine particles of solids or liquids.
Doctor Blade	A thin plate of metal, wood or rubber placed along the entire length of a roll or a cylinder to keep the surface clean or to apply crepe. Also used to control surface applications.
Draw	The difference in speed between two adjacent sections of the paper machine to compensate for stretch in the web of paper.
Dryers	The steam-heated cylinders over which the paper web is passed to be dried.
Dye pigments	Dyes that by nature are insoluble in water and can be used directly as pigments without any chemical transformation.
Electrostatic Precipitator	A device used to remove particulates from gas streams by application of a strong static electric charge.
Enzyme	A class of complex oranic substances that accelerate or catalyze specific chemical transformations such as the

modification of native starches for size press applications.

Fan Pump	A large pump used in the papermaking process to mix paper stock and water and deliver it to the paper machine headbox.
Fibre	The unit cell of plant growth.
Fiberizing	A process for the reduction of fibre aggregates to individual fibres from such sources as wood chips, pulp sheets dry broke, reclaimed paper stock and the like.
Fibrillation	The loosening of thread-like elements from the fibre wall
Fibrils	Thread-like elements of the cell wall of cellulose fibre.
Fillers	Materials used to fill voids which occur between fibres. Most printing paper except newsprint contains substantial amounts of filler. The term is also used for some interior, low grade fibre, layers in multiply board.
Filter	A process or device used to separate suspended solids from a liquid.
Filtrate	See Filter. Filtrate is usually either white water, black liquor or spent sulphite liquor.
Foils	Specially designed stationary members of the Fourdrinier table installed under the wire for controlled water removal and wire support. They replace table rolls.
Fold Test	The number of double folds that can be given a sheet of paper before it ruptures.
Formation	A term descriptive of the disposition of the fibres in a sheet of paper; "wild" if irregular; "closed" or "well closed" if uniform.
Fourdrinier Wire	An endless woven screen on which the stock is formed into a sheet of paper. Normally made of plastic nowadays.
Freeness	A measure of the rate with which water drains from a pulp suspension. Canadian Standard Freeness (CSF) is a standard test, used worldwide.
Free SO_2	In sulphite mill terminology, the portion of sulphur dioxide gas that is not combined with an alkaline base, but is instead is combined with water as sulphurous acid.

Furnish	The specific mixture of raw materials, both pulp and chemicals, from which a particular grade is manufactured, ready to be delivered to the paper machine.
Green Liquor	A liquid in the kraft process composed of the chemicals obtained from the recovery furnace. Primarily sodium sulphide and sodium carbonate in aqueous solutions.
Grits	The abrasive particles in the pulpstone which are responsible for the grinding action of the stone OR, in kraft mills, the inert lime rejected from the slaker.
Groundwood	Pulp produced by mechanically defibering wood with revolving grindstones or refining plates. See also "refiner groundwood"
Hard Sized	Paper which is treated with size to give maximum resistance to water penetration.
Headbox	A distributing chamber from which paper stock is spread evenly onto the wire of the paper machine.
Hemicellulose	Portion of wood fibre consisting of sugar-like substances intimately associated with cellulose in the fibre wall and removed mainly in the cooking process.
Hog Fuel	Term for wood waste fuel widely used in pulp and paper industry boilers. It includes some or all of the following: bark, sawdust, reject chips, sticks, branches, cutoffs and other saw mill and wood harvesting wastes. The major component is usually bark.
Jordan	A conical-shaped refiner used to cut and hydrate stock.
Kraft Pulp	Pulp produced by the kraft process (see pulping process description in Section 5.3). Also known as sulphate pulp.
King Roll	A large, driven, chilled iron roll on the bottom of the calender stack or super calender.
Knife Coater	A straight edge used to spread and control the amount of coating on the paper.
K. No. (permanganate number)	A chemical test performed on pulp to determine the degree of delignification.
Knotter	A type of screening equipment used to separate knots and other large, oversized and unwanted material from wood pulp.

Letterpress	A process of typographic (raised type) printing uses relatively viscous-bodied ink.
Machine Direction	The direction in the sheet of paper corresponding to the direction in which the machine ran when making the paper abbreviated to MD; the direction at right angles to it is called "cross machine direction", abbreviated CMD.
Machine Dry	Refers to paper at the dryness actually attained in normal paper machine operation. It is typically about 93% OD.
Machine Finish (MF)	The normal finish applied on a paper machine equipped with conventional dryers (differentiated from a yankee dryer).
Market Pulp	Pulp product such as bleached kraft softwood pulp sold to customers for machine furnish.
Medium Sized	Sized to give medium resistance to water penetration.
MST	Median Survival Time Provides a measure of relative toxicity of samples of effluent indicating the ability of test fish, frequently rainbow trout or Coho salmon to survive in samples of effluent.
Mullen	The bursting strength of a sheet of paper, or its resistance to puncture.
NCG	Non-condensable gases are gases emitted from several parts of the kraft pulping process which do not condense in the commonly installed condensing equipment. TRS and/or methanol are the predominant components.
Nip	The line of contact between two rolls.
NSSC	Neutral Sulphite Semichemical. A pulping process that uses a buffered (pH 8-10) alkaline cooking chemical - sodium or ammonium sulphite buffered with hydroxide or carbonate - to produce high yield pulp from hardwoods.
Opacity	The degree of non-transparency of paper.
Oven Dry (OD)	Pulp or paper dried in an oven by a standard laboratory procedure to the point where it contains no moisture. The term Bone Dry (BD) is commonly used synonymously. Oven dry weight divided by 0.9 equals the air dry weight in standard practice.

Oxidation Efficiency	Percentage reduction of sodium sulphide in the black liquor that is oxidized by blowing air or oxygen through the liquor, as applied to black liquor oxidation processes.
Particultate Emissions	Generaly this consists of all solid material discharged from a stack or vent. Specifically the particulate flow is defined by the standard test method described in the sampling and monitoring section of the manual. Particulate emissions are usually expressed as mg/m^3 or kg/h.
Pick Resistance	The ability of paper to resist surface failure due to the pull of the ink in printing.
Pigment	Finely divided mineral material which is insoluble in water, and used for colouring paper.
Pitch	Pitch is a material that can be solvent extracted from wood. It is largely a mixture of fatty and resin acids and unsaponifiable organic substances and is associated mainly with the ray-cells of the wood. Under certain conditions it accumulates on the Fourdrinier wire or in other equipment causing operating problems.
Plasticiser	Material used to make paper more pliable.
Precipitator (electrostatic)	A piece of equipment used to recover solids from a gas stream by the use of high voltage applied to plates or wires in the stream by the use of electrostatic forces
Pulpstone	A massive grindstone used in the mechanical defibring of wood to make stone groundwood pulp. It is manufactured by bolting replaceable abrasive segments to the periphery of a concrete wheel.
Queen Roll	A conventional roll in a calender stack located directly above the king roll.
Ream	Usually 500 sheets of paper; however, the size of paper varies, depending on the user and paper to which it is applied.
Recovery Furnace	A unit used to burn recovered cooking liquor to produce steam and to reprocess cooking chemicals. Frequently known as the recovery boiler. Refer to section 11.1.6.
Refiner Groundwood	A loosely used term referring to mechanical pulp made in a refiner instead of with the traditional grinder. Refer to description of mechanical pulping in process section. An equally common name is Refiner Mechanical Pulp (RMP).

Repulping	A process to slurry and disintegrate dry paper or dry pulp.
RMP	See refiner groundwood
Roll Coating	A process in which coating colour is applied to either one or both sides of a paper by transfer from a rubber applicator roll onto which the coating colour has been metered. This process may be carried out on or off the paper machines.
Rosin Size	The solution or dispersion obtained by treatment of a suitable grade of rosin with alkali.
Saveall	Equipment used to recover fibres and filler from the white water. Usually a wire-covered, rotating drum or wire-covered discs. Vacuum is employed to draw the water through the wire. Today the "wires" are usually plastic. There are several other types of save-alls working on a sedimentation or flotation principle.
Screen Room	A common term for screening and cleaning department which usually follows pulping operation.
Scrubber	A piece of equipment used to remove certain gases or solids from a gas stream utilising a spray of liquid, usually water or an aqueous solution of reactant.
Shives	A small bundle of fibres that has not been separated completely in the pulping operations.
Shrinkage	Term normally applied to the pulp loss in bleaching due to removal of lignin. Usually expressed as percent.
Size, or Sizing	The material added to paper to make the sheet resist the penetration of moisture.
Size Press	A vertically or horizontally oriented set of press rolls and equipment for spraying or otherwise applying size or other solutions to one or both sides of the sheet and removing the excess.
Slitter	The machine disc used to slit a paper sheet into specified widths.
Sludge Filter	A piece of equipment used to concentrate suspended solids recovered from an effluent by clarifier.
Smelt	The inorganic chemicals that are obtained in molten form from the recovery furnace.

Soda Loss	The loss of sodium salts due to imperfect washing of the pulp and recovery of sodium compounds in the chemical recovery system.
Spent Sulphite Liquor	Spent cooking chemicals and organics removed from wood in sulphite pulping process. Often called "red liquor" or "sulphite waste liquor"
Stiffness	A measure of the resistance of paper to bending.
Stock	A general term for a suspension of pulp fibre in water, normally implies a consistency between 0.2% and 15%. A papermaker's term for the beaten, refined and mixed materials (furnish) in a water suspension as supplied to the paper machine (also called "stuff").
Stock Preparation	A term for the operations which occur between pulping or bleaching and formation of the web on the paper machine operations which may include blending of several pulps, addition of colour, filler and other materials and chemicals.
Sublethal Toxicity	See toxicity
Suction Box	A narrow box with a perforated cover, mounted under the Fourdrinier wire. Vacuum maintained in the box draws water from the web. Similar, but much narrower boxes are used on wet felts to remove water from the felt.
Sulphate Pulp	A term often used for kraft pulp, especially in Scandanavian literature.
Sulphidity	In white liquor the percentage of sodium sulphide to sodium sulphide plus sodium hydroxide where all compounds are expressed as sodium oxide.
Supercalender	A machine consisting of metal and hard paper rolls through which paper is passed to improve the surface finish, producing a high finish.
Suspended Solids	Can be defined as the oven dry weight of material which can be removed from a sample of known volume by filtration through a standard filter paper. Normally expresssed as mg/L.
Sweat Roll	A hollow roll, cooled inside by a stream of water which causes slight condensation upon the periphery, used to restore moisture to the dried web of paper near the end of the paper machine.

Swimming Roll	Trade name for nondeflecting, variable crown roll, where a shell rotates around a stationary shaft. Oil pressure inside the shell compensates for the load. It usually replaces the king roll on the calender stacks, but can be used in any press position.
t	Abbreviation for tonne. As used in this manual this refers to a metric tonne of 1000 kg or 2205 lbs. When quoting precise data concerning tonnes of pulp, paper or wood it is essential to define the moisture content of the material (see AD, OD and Machine Dry in this Glossary). Much of the data in this manual consists of typical ranges or is approximate, so that the distinction is academic, and is often omitted in the interests of improving readability. In kraft pulp production, the ADt is most commonly used, whereas in newsprint production, machine dry tonne is most common. Detailed process calculations invariably use ODt.
Table Rolls	The rolls which support the paper machine wire and help drain water from the sheet.
Tackle	Replacement assembly of bars which provide the working surfaces in a refiner. (more commonly known as "refiner plates" in disc refiners).
Tear Resistance	The force required to tear a paper sample under specified conditions.
Tensile Strength	The resistance to breakage of paper when subjected to a pulling stress.
Toxicity	In the context of this manual, and also in most discussions of pulp and paper industry effluents in Canada, toxicity refers to acute toxicity to fish as defined in EPS 1-WP-80-1. This test measures the mortality of a sample of at least 5 fish over a 96-hour period. Sub-lethal toxicity refers to an undesirable effect of an effluent on fish which is not fatal (e.g., productivity or breeding may be inhibited).
TRS	Total Reduced Sulphur. A general term for sulphur gases emitted from kraft process excluding sulphur dioxide and trioxide. Generally considered to include hydrogen sulphide, dimethyl sulphide, dimethyl disulphide and methyl mercaptan. These gases are the principal cause of the classic kraft mill odour. They are generated by the reaction of sodium sulphide with some of the wood components. TRS is normally expressed as elemental sulphur.

Twin Wire	The forming section of a paper machine which uses two separate wires between which the headbox directs the stock with water removal occuring through both wires, thereby resulting in a less two sided sheet.
Two-sided Sheet	A term applied to a sheet of paper, the two sides of which are dissimilar in texture, colour or curl. The wire side may be more uniform in texture or the colour may be a lighter shade on the wire side due to higher reflectance.
Water Leaf	A completely unsized sheet that has a low water resistance.
Weak Wash	Recovered liquor from lime mud washing.
Web	The name applied to the full width of the paper sheet in the process of being formed, pressed, dried, finished or converted.
Web Rub Resistance	The ability of paper coating to withstand softening and rub-off from the combined action of fountain solution and blanket.
Wet Strength Resin	A synthetic additive used to impart strength to wet paper.
Wetting Agent	A substance which reduces surface tension improving the wettability of a solid surface by a liquid or a solution.
White Liquor	A liquid in the kraft process composed of the chemicals used in the digester to cook the wood chips. Primarily sodium sulphide and sodium hydroxide in aqueous solution.
White Water	Abbreviated ww, a general term for water removed from a pulp suspension and containing a small amount of fibre and/or additives. On a paper machine, the excess water drained through the wire from the furnish. The use of the term "white water" usually implies low dissolved solids content. Always white when white paper is produced, it contains pigments when running colours, and can be any colour.